

**FINAL REPORT—BIOCYANIDE FIELD  
DEMONSTRATION**

**MINE WASTE TECHNOLOGY  
PROGRAM ACTIVITY III,  
PROJECT 5**

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**Prepared for:**

U.S. Environmental Protection Agency  
Office of Research and Development  
National Risk Management Research Laboratory  
Cincinnati, Ohio 45268  
IAG ID No. DW89938513-01-0

and

U.S. Department of Energy  
Federal Energy Technology Center  
Pittsburgh, Pennsylvania 15236  
Contract No. DE-AC22-96EW96405

August 1998

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Program Manager



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## **Forward**

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of materials that if improperly dealt with, can threaten both public health and the environment. The U.S. Environmental Protection Agency (EPA) is charged by the Congress of the United States with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, EPA strives to formulate and implement actions leading to a balance between human activities and the ability of natural systems to support and nurture life. These laws direct EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The National Risk Management Research Laboratory (NRMRL) of EPA is responsible for planning, implementing, and managing research, development, and demonstration programs to provide an authoritative, defensible engineering basis in support of the policies, programs, and regulations of the EPA with respect to drinking water, wastewater, pesticides, toxic substances, solid and hazardous wastes, and Superfund-related activities. The Federal Energy Technology Center (FETC) of U.S. Department of Energy (DOE) has similar responsibilities to the NRMRL. FETC is one of the several DOE centers also responsible for planning, implementing, and managing research and development programs. This publication is one of the products of the research conducted by these two Federal organizations and provides a vital communication link between the researcher and the user community.

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## **Executive Summary**

This document is the final report for the Biocyanide Demonstration Project, a demonstration of a bioremediation technology for the detoxification of weak acid dissociable (WAD) cyanide in mine process solutions. The project included the construction and operation of a pilot-scale cyanide destruction unit at the Echo Bay McCoy/Cove Mine near Battle Mountain, Nevada. The project was conducted under Activity III, Project 5 of the Mine Waste Technology Program (MWTP).

The MWTP is funded by the U. S. Environmental Protection Agency (EPA) and is jointly administered by the EPA and the U. S. Department of Energy (DOE) Federal Energy Technology Center (FETC) through the Western Environmental Technology Office (WETO). Its primary objective is to advance the understanding of engineering solutions to national environmental issues resulting from past practices in mining and smelting of metallic ores.

MSE Technology Applications, Inc. (MSE) of Butte, Montana, is a prime contractor of DOE-WETO and is the owner and operator of the MSE Testing Facility and, therefore, responsible for preparation and implementation of this EPA demonstration project. The project was performed primarily under the MWTP with involvement from the Superfund Innovative Treatment Evaluation (SITE) program. Among the MSE responsibilities for this project was the selection of the technology and demonstration site, project management, demonstration oversight and operation, technical review, and report preparation. The developer of the technology, Pintail Systems, Inc., was responsible for providing the technology, process design, field operation, and assistance in report preparation. The contractor for the SITE program, Science Applications International Corporation (SAIC), was responsible for quality assurance/quality control (QA/QC) and assisted with field operation.

The purpose of this demonstration was to evaluate the performance of a pilot-scale technology capable of the removal and destruction of cyanide from the solution of a gold and silver ore heap-leach extraction process. The selected technology was a bioremediation technology furnished by Pintail Systems, Inc. The overall combined scope of this project was to design, construct, and test the operation and functionality of the biological technology at pilot scale. Results of the field demonstration are presented within this report. Over the 77-day test period, ALPKEM WAD cyanide, WAD cyanide, and total cyanide had average removal efficiencies of 78%, 82%, and 81%, respectively. The biotreatment process was concluded to be an effective technology for the destruction of cyanide and the removal of metals from a gold mine process wastewater.

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## Acronyms, Abbreviations, and Chemical Symbols

AgNO <sub>3</sub>	silver nitrate
CN	cyanide
DOE	U.S. Department of Energy
DOIT	Develop On-Site Innovative Technologies
DTP	Demonstration Test Plan
EM	Environmental Management
EPA	U.S. Environmental Protection Agency
FETC	Federal Energy Technology Center
FILE Flow	Injection Ligand Exchange
ft	feet
gpm	gallons per minute
HDPE	high-density polyethylene
LCS	laboratory control sample
LCS	laboratory control sample
MDL	method detection limits
mg/L	milligrams per liter
MS/MSD	matrix spikes/matrix spike duplicates
MSE	MSE Technology Applications, Inc.
MSHA	Mine Safety and Health Association
MWTP	Mine Waste Technology Program
NaH <sub>2</sub> PO <sub>4</sub>	sodium hypophosphate
NEPA	National Environmental Policy Act
NIST	National Institute of Standards and Testing
NRMRL	National Risk Management Research Laboratory
OSHA	Occupational Safety and Health Administration
ppm	parts per million
psi	per square inch
QA/QC	Quality Assurance/Quality Control
QAPP	Quality Assurance Project Plan
SAIC	Science Applications International Corporation
SAIC	Science Applications International Corporation
SITE	Superfund Innovative Technology Evaluation
SOP	standard operating procedure
TTP	Technical Test Plan
WAD	weak acid dissociable
WETO	Western Environmental Technology Office
Fg/L	micrograms per liter

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## 1. Introduction

This document is the final report for the Mine Waste Technology Program (MWTP), Activity III, Project 5, Biocyanide Demonstration Project. The MWTP is funded by the U.S. Environmental Protection Agency (EPA) and is jointly administered by the EPA and the U.S. Department of Energy (DOE) through an Interagency Agreement. This report details the project preparation, technology selection, site selection, field testing, and final results. The project was a field demonstration of an innovative technology to economically remove cyanide from a mine process solution using a biological method.

### 1.1 Project History

Cyanide is used in the mining industry to extract precious metals from ores and to improve the efficiency of metals separation in beneficiation. Use of this chemical in the industry has expanded in recent years due to increased use of heap leach technologies for gold and silver recovery. Cyanide can be an acute poison and has the ability to form strong complexes with several metals resulting in increased mobility of those metals. Therefore, cyanide can contribute to environmental problems in several ways.

Potential environmental problems resulting from cyanide use have led to the development of methods of degrading cyanide and cyanide complexes in mine wastewater and detoxification of depleted ore heaps. Most of these processes, which are relatively expensive to construct and operate, use chemicals to oxidize the cyanide and produce nontoxic levels of carbon dioxide and nitrogen compounds. For cyanide in ore heaps and tailings piles, a commonly used reclamation process is to rinse the solid materials with water or a chemical solution until the remnant cyanide in the solids is reduced to an acceptable level, a process that can take years to complete.

The scope of the demonstration was to design, construct, and test the operation and functionality of a treatment facility based on a biological destruction technology. Because of their experience and development work in the advancement of cyanide remediation, Pintail Systems Inc., was selected to be the technology provider for the demonstration.

The project initially caught the attention of the Western Governors Association's Committee to Develop On-Site Innovative Technologies (DOIT). The DOIT committee located the first potential demonstration site, the FMC Gold Company located near Gabbs, Nevada. However, the facility closed before the demonstration could be performed. Subsequently, another site was located.

The demonstration was conducted in a realistic environment at a gold and silver mine located 30 miles southwest of Battle Mountain, Nevada. The McCoy/Cove Mine is owned and operated by Echo Bay Mines, Ltd., and is an open-pit/heap leach mine. The source of the cyanide-laden water used for the demonstration was a slipstream from the solution mining process used to extract metals from ore heaps.

### 1.2 Project Criteria

#### 1.2.1 Primary Project Objectives

The technology developer has claimed a success rate of 90% in achieving  $< 1.0$  mg/l weak acid dissociable (WAD) cyanide (CN) concentration in the treated effluent. The project objective was to determine if this success rate falls within the 90% statistical confidence interval as determined from a total of 45 effluent samples collected during 90 days of successful operation. Thus, the objective was to determine if the developer's claim of 90%

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success rate (i.e., 0.9) falls within the statistical confidence interval. Therefore, if at least 38 of 45 samples analyzed exhibit WAD cyanide concentrations less than 1.0 milligram per liter (mg/L), then the project objective would be met. This is based on the minimum number of samples meeting the acceptance requirements ( $< 1.0$  mg/L WAD CN) based on the binomial distribution.

### ***1.2.2 Secondary Project Objectives***

In addition to the primary project objective, there were a number of secondary objectives which provided additional background data on the bioremediation process' operating characteristics, treatment capabilities, and costs. Secondary project objectives for the field test were:

- C Determine the effectiveness of the bioremediation process in reducing heavy metals in the process solutions.
- C Monitor the variation in WAD cyanide, total cyanide, and total metals in the treatment effluent over the test period.
- C Monitor the variation in WAD cyanide in the field using the Flow Injection Ligand Exchange (FILE) method.

- C Determine the percent reduction in WAD and total cyanides from the influent to the effluent over the test period.
- C Determine the loss of cyanide and metals in the control reactor.
- C Develop operating costs.

The critical parameter for this demonstration was the concentration of WAD cyanide in the treated solutions from the bioremediation process.

### **1.3 Project Schedule**

Initial field testing began in February 1997; however, it was suspended due to unanticipated high levels of cyanide in the process solution. Testing resumed on June 11, 1997 after an enlargement of the system was accomplished to compensate for the higher concentrations of cyanide. Testing continued until August 26, 1997, completing 11 weeks of technology demonstration.

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## **2. Demonstration Site Description**

The McCoy/Cove Mine was selected as the demonstration site for this project. The McCoy/Cove Mine is a working gold and silver mine in Lander County, Nevada, located 30 miles southwest of Battle Mountain, in central Nevada.

### **2.1 McCoy/Cove Mine Operation**

The McCoy/Cove Mine was purchased by Echo Bay Mines Ltd., in 1986. At that time, the McCoy Mine was the only known gold and silver deposit to exist on the property. Three months later a deposit of gold and silver was discovered approximately 1 mile from the McCoy Mine. The new deposit was called Cove. Mining of the Cove deposit began in 1988. Both mines are open pit operations with some underground mining at the McCoy Mine. Heap leaching and milling operations are both employed to economically optimize ore processing. Low-grade oxide ore is heap leached and the higher-grade oxides and the sulfides are milled. During 1996, the McCoy/Cove Mine produced 272,000 ounces of gold and 7.1 million ounces of silver.

### **2.2 Site Trending**

The mine site is situated on the east slope of a north-south mountain range in central Nevada. The open-pit mines and the mill operation and administrative buildings are located within the lower foot hills of this range. Heap leach piles extend from the base of the foot hills outward onto the flat lands to the east. All heaps have a gradual easterly slope with solution collection basins at the lower end. Leach-pad operation consists of a network of pipes supplying the leach application solution to the heaps and pregnant solution distribution to the metals extraction buildings. Solution ponds and pump houses are also located on the flat area.

The demonstration site was situated adjacent to one of the pump houses and pond complexes. This was an ideal location for the demonstration with easy access to the cyanide solution and convenient discharge of the treated solution (see Figures 2-1 and 2-2).



Figure 2-1. Demonstration site.



Figure 2-2. Discharge pond.

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### 3. Predemonstration Activities

Several preliminary activities were required by the MWTP of MSE Technology Applications, Inc. (MSE) and the technology developer before the demonstration could be conducted. These activities included technology selection, site selection, Quality Assurance Project Plan (QAPP), health and safety plan, and analytical laboratory selection.

#### 3.1 Technology Selection

Candidate water treatment technologies were evaluated and screened in the technology selection phase of the project. This screening produced a number of candidate technologies that could be functional under the imposed prioritization parameters (functionality, capital and operating costs, reliability, and innovation). The evaluation process is documented in *Issues Identification and Technology Prioritization Report - Cyanide, Activity I, Vol. 3*. Of the twenty-three technologies that were screened against various criteria, biodegradation showed the most promise in making cyanide removal cost effective and environmentally responsible.

#### 3.2 Site Selection

Several potential sites were identified as an initial step in this project. The selected site was the McCoy/Cove Mine located in central Nevada. An access agreement with the McCoy/Cove Mine owner and operator, Echo Bay Mines Ltd., was obtained to permit the installation and operation of the pilot-scale biocyanide demonstration unit. The discharge of treated water from the demonstration technology was piped to existing solution mining holding ponds and was allowed under existing mine permits. The equipment installation and operation fell under the jurisdiction of the Mine Safety and Health Association (MSHA) and was subject to applicable regulations.

#### 3.3 Quality Assurance Project Plan

A QAPP was developed for the Biocyanide Demonstration Project and submitted to the EPA's Office of Research and Development for review and approval. The QAPP was prepared by Science Applications International Corporation (SAIC) in alignment with the standards provided in "Preparation Aids for the Development of QA Project Plans," (EPA/600/8-91/003 through 006) February 1991. Additionally, it served as a "standard operating procedure" document for the sampling team, the sample preparation team, the analytical team, and the data reduction team. The QAPP document (SAIC Project No. 06-6193-07-5160-XXX) was approved by EPA National Risk Management Research Laboratory (NRMRL) and is available for review upon request.

#### 3.4 Health and Safety Plan

A health and safety plan specific to the Biocyanide Demonstration Project was developed to establish the procedures and requirements that were used to minimize health and safety risks to persons working at the demonstration site. The plan detailed responsibilities, personnel training, medical surveillance, site work practices, hazard evaluation, personal protection equipment, decontamination, and emergency response plan. In addition to this health and safety plan, activities were conducted in accordance with applicable regulations of the MSHA, the Occupational Safety and Health Administration (OSHA), the MSE Risk Management Manual, and applicable McCoy/Cove Mine policies. The Health and Safety Plan is available for review upon request.

#### 3.5 Experimental Design

In order to validate the primary project objectives and investigate the secondary objectives of the



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project, an experimental design was performed. The experimental design utilized sampling and analysis of the biotreatment process, as well as a control. A sampling strategy was performed as part of the experimental design. Quality control sampling formats were designed for the technology based on the demonstration test plan. Sample locations and time intervals between samples were established to aid in the identification of trends and to produce adequate data to evaluate the technology's overall performance. During the development stage of the sampling formats close scrutiny was given to the balance between adequate sampling and over sampling. The type of laboratory analysis for

each sample was established to ensure adequate data was available to identify related substance effects along with the concentration of the primary cyanide compound.

Additional field samples to be analyzed in the field and used to monitor the technology's day-to-day performance were included in each of the formats. The results of the analysis from these samples were recorded in the Biocyanide Project logbook. Noncritical temperature and pH measurements were also recorded in the logbook. The project-specific QAPP contains a detailed description of the experimental design.

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## 4. Demonstration Technology Description

As previously mentioned, an extensive search was undertaken to evaluate innovative technologies that could be applied to the cyanide problem. The selected technology was the biological destruction technology developed by Pintail Systems, Inc.

A pilot-scale system was constructed at the McCoy/Cove Mine to degrade cyanide in a leach-pad process stream. Pintail Systems, Inc., with assistance from MSE was the contractor responsible for the design, construction, and operation of the biological reactor system used to degrade the cyanide. To initiate the project, Pintail collected water samples from the mine site to isolate indigenous organisms capable of effectively degrading cyanide. Bioaugmentation studies were then performed at Pintail's Colorado Laboratory, in which bacteria were subjected to increasing concentrations of cyanide to select for the most capable organisms. The bacteria selected from these studies were used to perform bench-scale tests. The results from the bench-scale tests were used to design the pilot-scale system that was constructed at the mine.

### 4.1 Technology Configuration

The biotreatment system consisted of three process trains (see Figure 4-1). Two of these trains (#100 and #200) were biological treatment trains and the third train was the control train (#300). Each train consisted of an aerobic reactor followed by two anaerobic reactors and a small aerobic polishing reactor. The aerobic and anaerobic reactors were inoculated with aerobic and anaerobic microbiological cultures, respectively. The control train was not inoculated but was permitted to establish its own culture (i.e., the control train was not kept sterile). The two biotreatment trains were alternately fed the cyanide solution to be treated. During a train's offcycle, the solution would be prepared for the next treatment cycle by circulating a

nutrient/culture solution through the system. This was accomplished separately for the aerobic and the anaerobic reactors of the system. The control train processed the same cyanide solution as the treatment trains. The data from the control reactor was compared with that of the on-line treatment train and provided a measure of performance. Figures 4-2 and 4-3 are photographs of the biocyanide system.

#### 4.1.1 General System Operation

The biotreatment technology consisted of a proprietary biological culture of microorganisms, immobilized on a porous ceramic filtration media. Two identical biological treatment trains of aerobic and anaerobic bioreactors were operated in an on/off, inoculation/treatment cycle, parallel to a control aerobic/anaerobic, uninoculated, porous, ceramic filtration media. The anaerobic reactors were operated as plug-flow reactor systems while the aerobic reactors operated as trickling filters.

The process water to be treated by the biotreatment system was taken from a leach-pad process system as a slipstream at a flow rate of less than 0.15 gallons per minute (gpm). A pressure regulator was employed to reduce the pressure of the slipstream to 20 pounds per square inch (psi) before entering the biotreatment system. Additional precautions were provided against overpressure with the use of a pressure switch and an emergency shutoff valve. The process water entering the building passed through another emergency shutoff valve before being distributed to the process columns. Flow meters and control valves regulated the flow rate to each column. The aerobic reactors were operated in downflow configurations, while the anaerobic reactors were operated in upflow configurations. The discharge from the anaerobic reactors was piped to a small aerobic polishing reactor. Effluent from the polishing reactor flowed to a nearby holding pond.

Air was injected near the base of the aerobic and polishing reactors to ensure a complete aerobic reaction. Each process column employed a small metering pump that provided recirculation of the process solution from the outlet of the second anaerobic reactor back to the inlet of the respective aerobic reactor. A treatment train was typically operated on-line, treating the process solution for 24 hours. The treatment trains were then switched and the off-line train was flushed with clean water. After the flushing cycle was complete, a combination solution of aerobic and anaerobic culture and nutrients were circulated through their respective reactors refreshing the

system for the next on-line operation. The treatment bacteria were maintained as live-cultures in a continuous culture system. Additional details of the operation are furnished in Pintail Systems Inc.'s standard operating procedure (SOP).

#### **4.1.2 Equipment and Accessories**

The biocyanide treatment system was installed in a transportable steel chemical safety storage building. Overall measurements of building were 8-feet (ft)-wide by 16-ft-long and 8-ft- high. Self-contained heating and ventilation provided environmental control for the structure. A grated floor supported the equipment and with the base of the structure, provided 8 inches of spill containment.

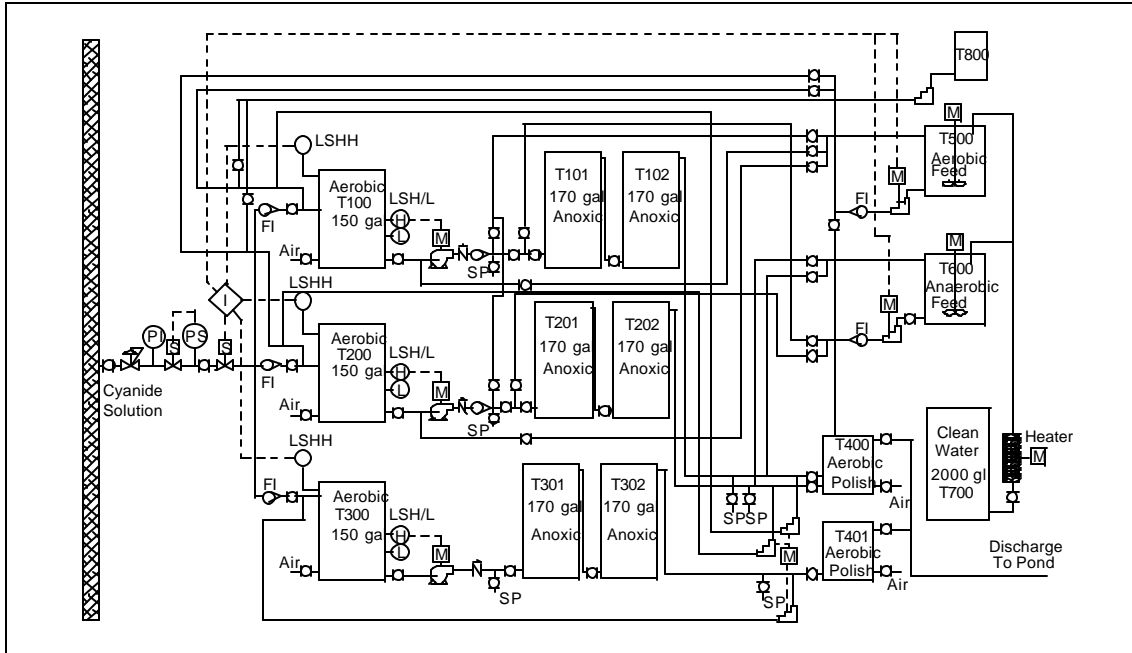
**Table 4-1. Biocyanide System Specifications**

Number of treatment trains	2- treatment, 1 - control
Reactors per treatment train	1 - aerobic, 2 - anaerobic, 1 - polishing
Column capacity	~545 gallons
Reactor capacity	150 gallons aerobic, 340 gallons anaerobic, 55 gallons polishing
Operating pressure	Aerobic ambient, anaerobic 2.6 psi
Reactor construction	Polypropylene
Reactor substrate	Ceramic media
Reactor liquid fill fraction	33%

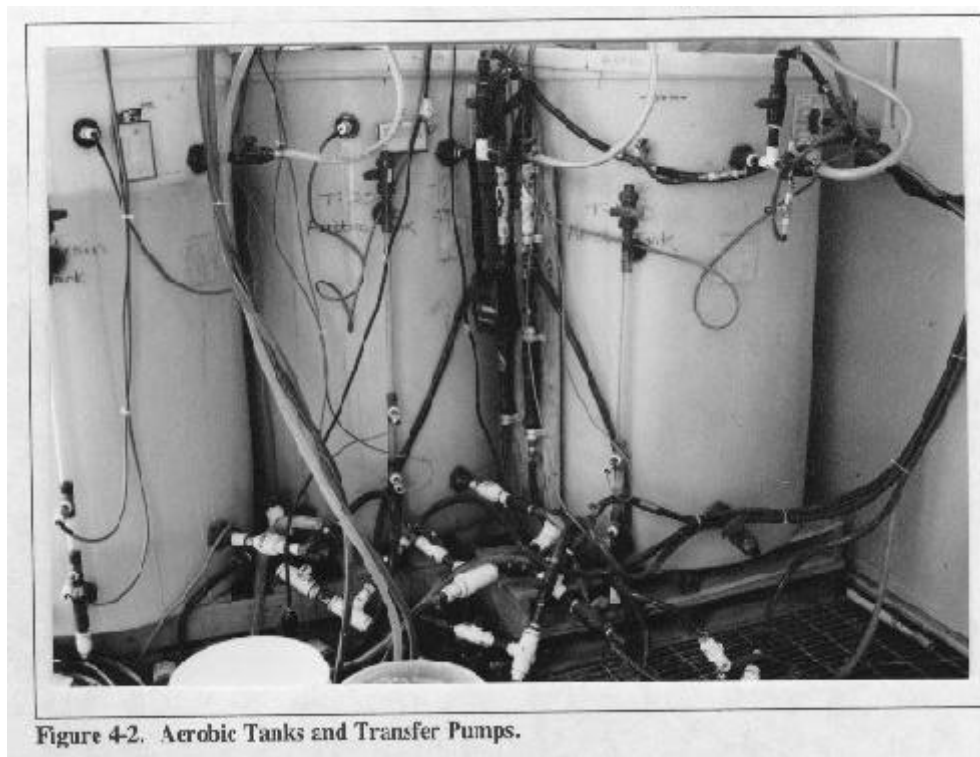
The following is a list of equipment that was necessary to support the biocyanide system operation.

**Table 4-2. Support Equipment**

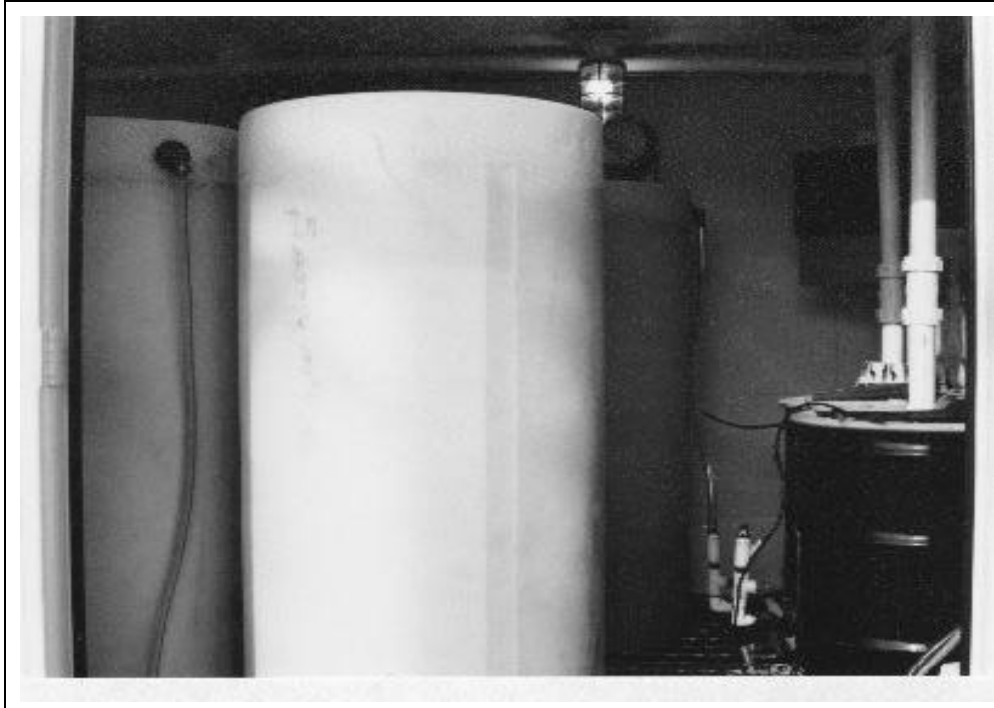
Clean water storage tank	2,000 gallons polyethylene
Aerobic live-culture holding tank	150 gallons polyethylene
Anaerobic live-culture holding tank	150 gallons polyethylene
Culture circulation pumps	2 each, 60 Hertz, 1 Phase, 115 Volt
Process recirculation pumps	3 each, 60 Hertz, 1 Phase, 115 Volt
Process level control	3 each, 60 Hertz, 1 Phase, 115 Volt
Air compressor (valve operation)	3 hp, 115 vac
PVC pipe and valves	1 inch and ½ inch
Equipment power	115 vac, 1 pH, 30 amp



**Figure 4-1. Process Schematic.**



**Figure 4-2. Aerobic Tanks and Transfer Pumps.**



**Figure 4-3. Anaerobic and polishing tanks.**

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## 5. Quality Assurance and Control

During Activity III, Project 5, of the MWTP, several activities related to quality assurance/quality control (QA/QC) were performed to assure that procedures outlined in the project-specific QAPP were followed and that quality data was generated for the project. SAIC had the responsibility for QA/QC oversight/ activities for the project, which include:

- Preevaluation of MSE-HKM Laboratory;
- Verification study for field cyanide analysis;
- QA review of the field demonstration;
- QA review of laboratory activities; and
- Performance evaluation of MSE-HKM Laboratory.

### 5.1 Preevaluation of MSE-HKM

#### Laboratory

In preparation for Activity III, Project 5, a pre-evaluation of the MSE-HKM Laboratory was performed by Joseph Evans, the SAIC QA Manager for the SITE Program on September 26, 1995. Cyanide in aqueous matrices was the most critical analysis for the project; therefore, the review focused on that analysis. The following items were reviewed during the preevaluation:

- chain of custody procedures, sample receipt, and sample storage;
- analytical methods for cyanide (total and WAD);
- management systems and corrective action procedures;
- general laboratory facilities;
- general distillation setup, available glassware, and hoodspace;
- colorimeter calibration and associated QC checks;
- titration determinations;
- second source standard checks;

- matrix spikes/matrix spike duplicates (MS/MSD) and control limits;
- laboratory control sample (LCS) determinations;
- analysis of particulate matter;
- dilutions and concentrations covered in colorimetric and titration determinations;
- standard preparation, storage and logbooks; and
- method detection limits (MDLs) and MDL studies.

In the majority of the areas reviewed, no concerns were identified; however, concerns were identified in the areas of sample receipt, standard preparation, and titration determination, along with concerns and corrective actions taken are briefly discussed below.

#### 5.1.1 Sample Receipt

**Concern:** Project Manager oversight of projects is nonroutine based upon discussion at the time of the review. Most samples are inspected only by the sample custodian, and in most instances, a subjective judgement is made concerning the condition of samples at the time of receipt. A sample receipt checklist is available but not strictly followed. Nonconformances associated with sample conditions at the time of receipt are reported to the client, or in some instances, the Project Manager at the laboratory.

**Corrective Action:** A laboratory Project Manager was assigned to the project with the responsibility of ensuring that QC requirements for the project were met. For sample receipt, this

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includes documenting the conditions of samples upon receipt at the laboratory by completing the sample receipt checklist and placing a copy in the project file.

### **5.1.2 Standard Preparation**

Two concerns in the area of standard preparation were identified:

1. **Observations and Concerns:** Pyridine-barbituric acid is prepared every 3 weeks. Sodium hypophosphate ( $\text{NaH}_2\text{PO}_4$ ) is also prepared approximately every 3 weeks and Chlorimine-T is prepared with every new batch of samples. The cyanide standard of 1,000 mg/L was 1-year-old, and a working solution was prepared from it for every analysis. One concern was there were no standard logs or records showing when these standards had last been prepared or the exact preparation methods and concentrations. In addition, labels were missing on the standards indicating a preparation date, expiration date, sample preparers' initials, etc., and some labels that did exist were incorrect often indicating the wrong preparation date.

**Corrective Action:** The laboratory immediately started to keep standard logs and also began to verify the 1,000 mg/L cyanide standard with a silver nitrate ( $\text{AgNO}_3$ ) titrant on a weekly basis, as it has a tendency to breakdown over time.

2. **Observations and Concerns:** For colorimetric determination, routine analysis at the laboratory used three standards and a zero point. The concentrations for the standards were 10, 100, and 200 micrograms per liter (Fg/L). (This range appeared appropriate.) The QAPP requires four standards and a zero point. Color development time should also be

standardized and recorded according to method specifications (color development time should be more than 8 minutes but no longer than 15 minutes).

**Corrective Action:** Several standards at concentrations of 5, 10, 25, 100, 150, 200, 300, and 400 Fg/L were added to comply with the QAPP. A different method was also used that does not require color development time to be standardized or recorded.

### **5.1.3 Titration Determination**

1. **Observations and Concerns:** The primary purpose of the titration determination is for confirmation of concentrations above 1 mg/L. All samples are first determined colorimetrically and those with concentrations above 1 mg/L are then determined by titration. The titrant  $\text{AgNO}_3$  had been purchased commercially, but concentration has never been verified.

**Corrective Action:** A second source standard was purchased to independently verify the concentration of the  $\text{AgNO}_3$ . The second source standard was titrated against a standard and the two separate titrants were compared.

### **5.1.4 Additional Recommendations**

1. MDLs are determined using the 100 Fg/L standards. The lowest standard, 10 Fg/L, should be used.
2. An additional interference check for sulfide was recommended using lead acetate paper to check for the presence of sulfide. If sulfide is present, excess bismuth nitrate should be added to the sample prior to distillation.
3. The laboratory SOP for cyanide analysis stated that sulfamic acid should be added for

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nitrate/nitrite interferences. This is correct for total cyanide determinations, but is not needed for WAD cyanide determinations. Therefore, the SOP should reflect this difference. The MSE-HKM Laboratory initiated appropriate corrective actions to address the above recommendations.

## **5.2 Verification Study for Field Cyanide Analysis**

Following the initial analysis of samples by the MSE-HKM Laboratory and Pintail Systems, significant discrepancies were discovered to exist between the laboratory and field analysis, particularly at the effluent location, which was the critical sampling location for data to support the project objectives. To correct the problem SAIC personnel worked with Pintail Systems personnel to validate the cyanide analytical procedure to be used in the field (EPA Draft Method 1677--Ligand Exchange/Flow Injection/Amperometric Technique for Available Cyanide Analysis) during the week of March 10, 1997. The field procedures were standardized to make the laboratory analysis and the field analysis as comparable as possible, as were sample collection and preservation procedures.

As a result of the study, it was concluded that the results met method and QAPP requirements. The ALPKEM instrument used for the analysis exhibited a high degree of precision with less stable accuracy. The recommendations from the verification study were summarized in a comprehensive SOP written for subsequent cyanide analysis at the mine site.

After the field procedure was standardized with the SOP, the comparison between field and laboratory results were excellent (within 5%) for effluent samples, but less precise for influent samples (within 25%).

## **5.3 QA Review of the Field Demonstration**

A technical systems review was conducted by personnel from NRMRL-QA in June 1997. Three findings and six observations were identified during the review. Most of the findings and observations were immediately implemented into a revised QAPP. The findings and observations and corrective actions are summarized below:

- 1. Finding:** The field auditor noted there was possible aeration of cyanide samples upon collection and, therefore, a potential for loss of cyanide.

**Corrective Action:** Field personnel were instructed to minimize headspace and collect the sample by allowing the liquid from the tap to flow down the sides of the collection container. The high pH of the samples (9.5 to 10) probably minimized any possible volatile loss of cyanide.

- 2. Finding:** The auditor noted that samples were not shipped to the laboratory on a specific laboratory collection day because of process upset caused by operator error.

**Corrective Action:** It was decided that all future samples would be sent to the laboratory as designated in the QAPP schedule unless all parties involved agreed the samples should not be submitted to the laboratory.

- 3. Finding:** Recovery of a spiked blank for field analysis was not within QC specification.

**Corrective Action:** This QC check was not significant because no samples were analyzed with this calibration curve; however, the QC specification has been relaxed to 75%-125% recovery as per the auditor's suggestion.

- 4. Observation:** SOP for field analysis does not specify procedures for removal of sulfide interference. Also, testing of sulfide with lead



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acetate paper was not implemented consistently.

**Corrective Action:** Both of these issues are discussed in the revised QAPP. Removal of sulfide interference is being accomplished using lead acetate solution. Lead acetate paper will be used consistently by field personnel as designated in the SOP.

5. **Observation:** Conductivity measurements were not taken in the field.

**Corrective Action:** It was decided by all parties involved in the project that this measurement was not necessary and was probably only in the original QAPP because of carryover from another document. This measurement has been removed from the QAPP.

6. **Observation:** Field equipment blanks addressed only the sample filtration step and did not take into account use of the pH meter. The order of pH measurements was observed to be high level samples to low level samples.

**Corrective Action:** Both of these concerns were discussed with field personnel. More representative field blanks and pH measurements were taken from low level to high level samples similar to the order used during sample filtration.

7. **Observation:** The auditor noted that dissolved oxygen concentrations were not monitored in the aerobic treatment tank.

**Corrective Action:** This procedure was changed and flow meters were installed to bleed air into the aerobic tanks at a precise rate.

8. **Observation:** The auditor noted that the

QAPP was outdated and should be updated.

**Corrective Action:** A revised and updated QAPP was prepared by SAIC and distributed to all project participants.

#### 5.4 QA Review of Laboratory Activities

In addition to the QA review of the field demonstration, a QA review of the MSE-HKM Laboratory was also performed. One finding and two observations were noted by NRMRL personnel during a review of the MSE-HKM Laboratory in June 1997.

1. **Finding:** Matrix spike levels were set at 1 part per million (ppm) based upon the expectation that effluent samples would be below 1 ppm.

**Corrective Action:** To correct this problem the SAIC QA Coordinator began communicating appropriate spiking levels to the Laboratory based on field analyses.

2. **Observation:** The QC requirements for metals analysis (noncritical) specified in Table 7-1 of the QAPP did not match the Laboratory's operations.

**Corrective Action:** The QAPP has been changed so that QC requirements match the Laboratory's operations.

3. **Observation:** The metal analyte list was not clarified with the laboratory.

**Corrective Action:** A new list of metal analytes is included in the revised QAPP.

Following the audit, all corrective actions necessary in the field and laboratory were followed up on to verify that all procedures were being implemented as recommended.

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## **5.5 Performance Evaluation of MSE-HKM Laboratory**

In addition to the QA reviews at the MSE-HKM Laboratory is also subjected to performance audits periodically. The EPA through the State of Montana submits the performance evaluation samples to the MSE-HKM Laboratory. The results of the most recent cyanide performance evaluation sample were approved by EPA on May 9, 1997. The true value was 0.080 mg/L, and the MSE-HKM Laboratory reported a value of 0.072 mg/L, which was well within the acceptance limits of 0.0522-0.107 mg/L cyanide.

## **5.6 Field Sampling and Analysis**

### ***5.6.1 Techniques and Methods***

All sampling, storage and transporting were completed by following all procedures outlined in the project-specific QAPP. Samples were taken by opening the prescribed sample port and flushing the piping and port for several seconds to ensure that the sample was representative of the product. Sample bottles were high-density polyethylene (HDPE) provided by the MSE-HKM Laboratory. The sample bottle was then rinsed three times with a sample product and the sample bottle was filled after the third rinse. Sample bottle lids and labels were secured and sealed with para-film and cellophane tape.

Temperature and pH samples were taken after allowing several seconds of product to flow from the sample port in order to stabilize the temperature in piping and ensure a fresh product. Sample bottle temperature was stabilized by filling each bottle three times with a sample product. Temperature was measured immediately after the third "rinse" using a hand-held mercury thermometer. Temperature samples were taken at the sample port at the time designated on the sample data form. The pH was

measured using an Accumet 1003 meter with a temperature-compensating pH probe. The Accumet was calibrated daily, using up-to-date pH buffers, according to procedures outlined in Measurement Procedures Handbook.

### ***5.6.2 Field Sample Analysis and Data Recording***

In addition to the QC sampling for laboratory analysis, it was necessary to take samples for field analysis to ensure the technology was within its operational parameters. These field samples were analyzed with instruments and reagent test sets using EPA accepted methods and equipment manufacture procedures. Results of these field analysis were recorded in the Biocyanide Project logbook. Additionally, this logbook was used for recording process pH levels, temperatures and flow rates.

### ***5.6.3 Instrument Accuracy***

The performance evaluation of the technologies demonstrated was in part a function of the instrument quality and its calibrated accuracy. Instruments installed for the monitoring of temperature and flows were selected to obtain an overall accuracy capability of at least 1% of the full-scale span adjustment. Calibration of these instruments was accomplished prior to the demonstration and at its conclusion. A calibration history card was initiated for each instrument showing its accuracy, five-point calibration data, date of calibration, and test equipment National Institute of Standards and Testing (NIST) traceability.

A characterization and error analysis was performed to identifying the mean and standard deviation for each measurement instrument. This developed a 95% confidence interval for each measurement. An outline of the calibration requirements is shown in Table 5-1 below.

**Table 5-1. Calibration Requirements for Process Field Measurements**

Parameter	Measurement Classification	Process Instrument	Calibration Procedure	Frequency of Calibration	Expected Range/Acceptance Criteria
Process water inlet flow rate for treatment column #100	Critical	Volumetric flow rate	Manufacturer's procedure using NIST traceable test equipment.	6 months for flow instrument with scheduled verification of test equipment at standards lab <sup>1</sup>	0.50 gpm +/- 0.1 gpm
Process water inlet flow rate for treatment column #200	Critical	Volumetric flow rate	Manufacturer's procedure using NIST traceable test equipment.	6 months for flow instrument with scheduled verification of test equipment at standards lab <sup>1</sup>	0.50 gpm +/- 0.1 gpm
Process water inlet flow rate for control column #300	Critical	Volumetric flow rate	Manufacturer's procedure using NIST traceable test equipment.	6 months for flow instrument with scheduled verification of test equipment at standards lab <sup>1</sup>	0.50 gpm +/- 0.1 gpm
Process water inlet temperature column #100, #200 and #300	Noncritical	Type T, 1/8", enclosed thermocouple. Readings taken with NIST traceable test equipment. Curve fit for type T TC.	Element characterized to +/- 1E C using lab standard and referenced to ITS-90 reference tables.	Certified to +/-1EC. Scheduled verification of test equipment at standards lab <sup>1</sup> .	Inlet and Outlet 0 - 50E C +/- 1E C

<sup>1</sup> The standards used for calibration of equipment at WETO are verified by the Secondary Standards Lab on a routine, scheduled basis.

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## 6. Results and Discussion

Operation of the pilot-scale biocyanide test unit began on June 11, 1997 and operated for 77 days until August 26, 1997. A summary of data collected during this time period is presented in the following sections. Raw data is located in Appendix A. A description of the sampling procedure, frequency, and sampling locations can be found in the project-specific QAPP.

The chemistry of cyanide in the environment is very complex. Numerous cyanide compounds and their derivatives can be found in the process solutions, waste effluents, and tailings generated by the cyanidation processes. In general, they can be classified as free cyanide, simple cyanide, and complex cyanide. Illustrative examples of each of these types of compounds are shown below:

Free Cyanide –  $\text{CN}^-$  or  $\text{HCN}$ ;

Simple Cyanide –  $\text{A}(\text{CN})_x$ , where A is a metal; and

Complex Cyanide –  $\text{A}_y\text{M}(\text{CN})_x$ , where A is an alkaline metal and M is a heavy metal.

The relative stability of these cyanide complexes ranges from weak to strong. Total cyanide analysis includes simple and complex cyanide species, which include the weak and strong metal cyanide complexes such as the iron cyanides. Weak acid dissociable cyanide analysis includes the simple and weak metal-cyano complexes but not the stronger complexes.

### 6.1 ALPKEM WAD Cyanide

Cyanide was measured in the field with the use of a ALPKEM cyanide analyzer. ALPKEM, a division of OI Analytical, the CN Lab analyzer, model 3202. This method of cyanide analysis is referred to as the FILE method, which is undergoing final review for acceptance as EPA

Method 1677. The method provides a mere rapid analysis of cyanide contaminated waste streams analysis than through the distillation method. Field cyanide values were measured on a near daily basis throughout the field demonstration. Figure 6-1 and Table 6-1 present the ALPKEM WAD cyanide results. Influent, effluent, and control values are depicted.

WAD cyanide was substantially removed from the mine process water during the field demonstration of the biocyanide pilot-scale unit. The average influent concentration of ALPKEM WAD cyanide was 265 mg/l, while the average effluent concentration was 59.5 mg/l. The percent removal of WAD cyanide as measured by the ALPKEM analyzer ranged from 38% to near 100%. An average removal efficiency over the entire test period of 78% was observed. A 70% removal was achieved in 70% of the samples; an 80% removal was achieved in 54% of the samples; and a 90% removal was achieved in 32% of the samples collected. During the latter portion of the test period (7/18/97 to 8/26/97) when the system was operating more optimally, an 88% average removal efficiency was observed. The average removal efficiency for the control reactor was -1.9% indicating ALPKEM WAD cyanide was not removed in the control reactor.

### 6.2 Distillation WAD Cyanide

WAD cyanide values were measured by the distillation method according to the project-specific QAPP at the MSE-HKM Laboratory. This method of analysis is presently the EPA-accepted method. WAD cyanide values were not collected as frequently as the ALPKEM WAD cyanide values. Figure 6-2 and Table 6-1 present the distillation WAD cyanide data collected during the field demonstration.

WAD cyanide measured by the distillation method

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was substantially removed during the field demonstration. The average influent concentration was 242 mg/l, while the average effluent concentration was 44.3 mg/l. The percent removal of WAD cyanide through the biocyanide pilot-scale unit ranged from 45% to nearly 100%. An average removal efficiency over the entire test period of 82% was observed. A 70% removal was achieved in 77% of the samples; an 80% removal was achieved in 60% of the samples; and, a 90% removal was achieved in 37% of the samples. During the latter portion of the test period (7/18/97 to 8/26/97) when the system was operating more optimally, an 89% average removal efficiency was observed. The average removal efficiency for the control reactor was -8.1% indicating WAD cyanide was not removed in the control reactor.

### 6.3 Total Cyanide

Total cyanide was measured with the same frequency as distillation WAD cyanide according to the project specific QAPP. These samples were also analyzed at the MSE-HKM Laboratory. Figure 6-3 and Table 6-1 present the total cyanide data collected during the field demonstration.

Total cyanide was also substantially removed from the mine process water during the field demonstration. The average influent concentration of total cyanide was 284 mg/l, while the average effluent concentration was 57 mg/l. The percent removal of total cyanide ranged from 45% to near 100%. An average removal efficiency over the entire test period of 81% was observed. A 70% removal was achieved in 74% of the samples; an 80% removal was achieved in 60% of the samples; and, a 90% removal was achieved in 34% of the samples. During the latter portion of the test period (7/18/97 to 8/26/97) when the system was operating more optimally, an 89% average removal efficiency was observed. The average removal efficiency for the control reactor was 0.77% indicating total cyanide was not

removed in the control reactor.

### 6.4 Metals

Several metals were collected and analyzed during the field demonstration and the samples shipped to the MSE-HKM Laboratory according to the project-specific QAPP. The following metals were analyzed: arsenic, cadmium, cobalt, copper, iron, manganese, mercury, nickel, selenium, silver, and zinc. This data is presented in Table 6-2 and in Figures 6-4 through 6-14, respectively. Each data point on the graphs indicates samples collected and combined from three separate sampling events.

In general, metals concentrations in the effluent samples were substantially lower than in the influent process mine water. Metal removal occurred through biomineralization, a process by which microorganisms mediate and catalyze inorganic reactions to form new mineral assemblages. Biomineralization is a surface process associated with microorganism cell walls and excreted cell products where the remineralization occurs. A biomineral is defined to include both biologically formed authigenic minerals (pyrite, etc.) and complex biostabilized materials that are often clay- or gel-like (iron, aluminum) silicates, sulfides and oxides of variable composition that are presumed to be thermodynamically metastable phases. Thus, metal removal from the process water occurred, when microorganisms within the bioreactors formed new mineral assemblages thereby reducing the mobility of metals. In addition to biomineralization, sulfate reducing bacteria within the bioreactors are credited with forming insoluble metal sulfide precipitates through their production of hydrogen sulfide, which also contributed to the removal of metals from the process water.

The average removal efficiencies for cadmium, mercury, silver, and zinc were very high— 94%, 97%, 97%, 96.5%, respectively. These removal

efficiencies were dramatically higher than those observed in the control reactor— 2.2%, 13.4%, -6.4%, -4.1%, respectively. The average removal efficiency for arsenic was 85%, while a 4.9% removal efficiency was observed in the control reactor. Selenium, copper, and nickel had removal efficiencies of 67%, 66%, and 55%, respectively. Again, these removal efficiencies were dramatically higher than those observed in the control reactor—4.7%, -8.4%, -2.2%, respectively. The average removal efficiency for cobalt was 30%, while a -9.6% removal efficiency was observed in the control reactor. Two metals, manganese and iron, had negative removal efficiencies; i.e., concentrations in the effluent were higher than in the influent. The presence of these metals in the effluent is attributed to the leaching of these metals from the bioreactor

substrate. It should be noted that the metals concentrations in the influent mine process water varied throughout the field demonstration. These concentration changes were likely caused by changes in the ore processing and milling.

## 6.5 pH

The pH was measured during the field demonstration. Samples were collected and analyzed in the field using a hand-held pH analyzer. The samples were collected and the analyzer was calibrated according to the project-specific QAPP. The pH data is presented in Figure 6-14.

The pH of the effluent samples was consistently near neutral ( $7.9 \pm 0.4$ ,  $n = 65$ ). As with most heap leach operations, influent mine water tended to be basic (average pH  $9.7 \pm 0.3$ ). The pH in the control reactor effluent ( $9.6 \pm 0.4$ ) was consistent with the influent indicating the control reactor did not alter the pH of the process water. The biological process was successful in lowering the pH to neutral values.

**Table 6-1. Cyanide Results**

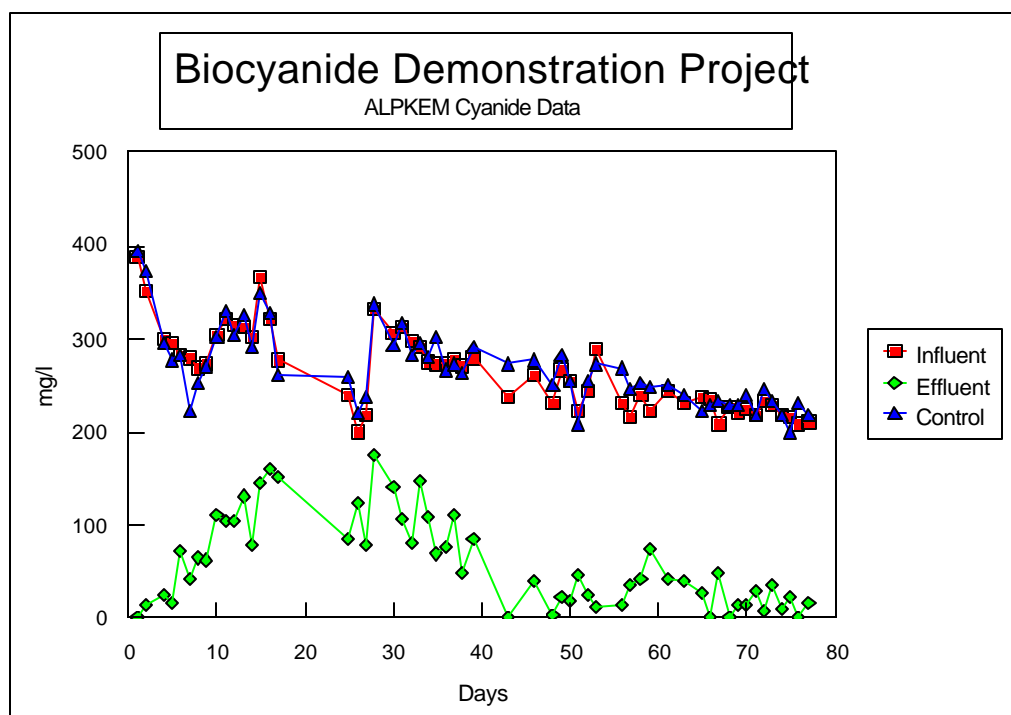
	Total CN	WAD CN	ALPKEM WAD CN
<b>Entire Test Period (6/11 - 8/26/97)</b>			
Total number of samples	36	36	57
Average influent concentration (mg/l)	$284 \pm 46$	$242 \pm 59$	$265 \pm 43$
Average control concentration (mg/l)	$287 \pm 90$	$251.3 \pm 58.8$	$269 \pm 41$
Average effluent concentration (mg/l)	$57 \pm 46.1$	$44.3 \pm 34$	$59.53 \pm 47.95$
90% success with 90% confidence limit (mg/l)	103.1	78.3	107.48
Average percent removal (effluent)	$80.5 \pm 15.4$	$81.6 \pm 14.7$	$78.3 \pm 16.1$
Average percent removal (control)	$0.77 \pm 35.5$	$-8.1 \pm 28.9$	$-1.9 \pm 6.5$
Percentage with removal > 90%	34	37	32
Percentage with removal > 80%	60	60	54
Percentage with removal > 70%	74	77	70
<b>Test Period (7/18 - 8/26/97)</b>			
Number of samples	21	21	28
Average influent concentration (mg/l)	$258 \pm 24$	$217 \pm 42$	$236 \pm 21$
Average control concentration (mg/l)	$276 \pm 100$	$225 \pm 52$	$244 \pm 23$
Average effluent concentration (mg/l)	$30.1 \pm 24.9$	$25.5 \pm 20.7$	$27.48 \pm 21.05$
90% success with 90% confidence limit (mg/l)	55.1	46.2	48.53

Average percent removal (effluent)	88.7 ± 9	88.8 ± 9	88.4 ± 8.7
Average percent removal (control)	-1.85 ± 41.1	-7.7 ± 32	-3.9 ± 6.2

**Table 6-2. Metals Results**

	Number of Samples	Average influent conc. (Fg/l)	Average effluent conc. (Fg/l)*	Average effluent removal (%)	Average control conc. (Fg/l)	Average control removal (%)
As	12	332 ± 35	46.8 ± 24.7	85.2 ± 8.5	315 ± 45	4.9 ± 10.7
Cd	12	51 ± 36	2 ± 0.1	94.1 ± 3.2	51 ± 37	2.2 ± 11.5
Co	12	158 ± 151	60 ± 20	30 ± 52.7	176 ± 175	-9.6 ± 23.9
Mn	12	24.2 ± 19.5	70.6 ± 33.7	-599 ± 769	4.8 ± 2.7	74.8 ± 17
Hg	11	179 ± 23	5.1 ± 3.6	97 ± 2.2	155 ± 26	13.4 ± 9
Se	12	255 ± 61	84.9 ± 47.8	67.4 ± 17.2	233 ± 39	4.7 ± 21.9
Ag	12	882 ± 667	15.4 ± 7.4	97 ± 2.4	757 ± 489	-6.4 ± 48.9
Zn	12	29 ± 24	0.057 ± 0.22	96.5 ± 2.3	30.1 ± 26	-4.1 ± 8.7
	Number of Samples	Average influent conc. (mg/l)	Average effluent conc. (mg/l)	Average effluent removal (%)	Average control conc. (mg/l)	Average control removal (%)
Cu	12	150 ± 28	53 ± 44	66.4 ± 23.8	156 ± 29	-8.4 ± 34.9
Fe	12	1.51 ± 0.86	2.23 ± 2.01	-60.9 ± 131.1	1.1 ± 0.7	17.4 ± 42
Ni	12	1.65 ± 0.11	0.75 ± 0.30	55.3 ± 15.9	1.69 ± 0.1	-2.2 ± 4.8

\* When the effluent value was below the detection limit, one-half the detection limit was used as a real number.



**Figure 6-1. ALPKEM cyanide data.**

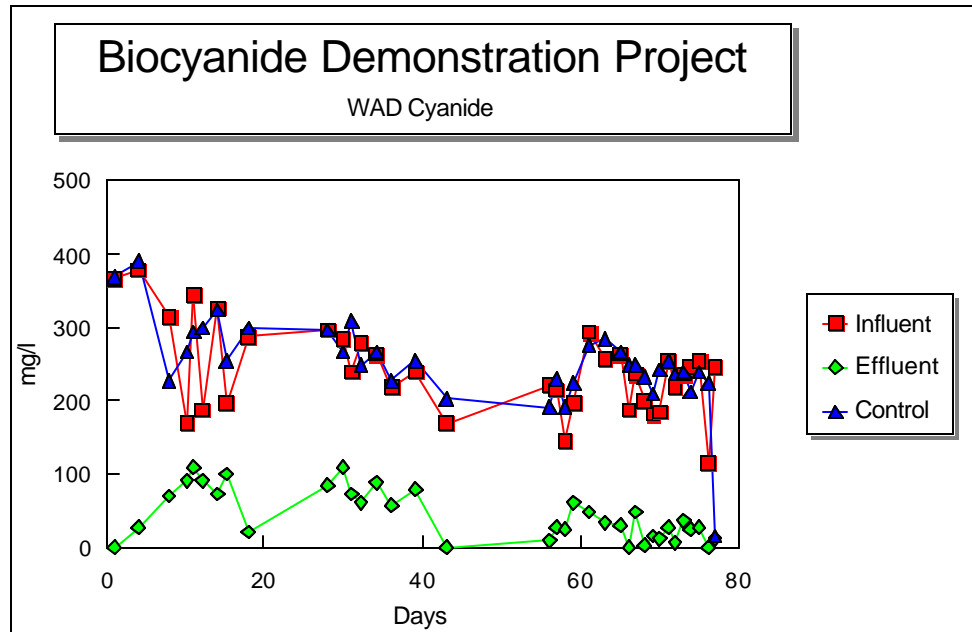


Figure 6-2. WAD cyanide.

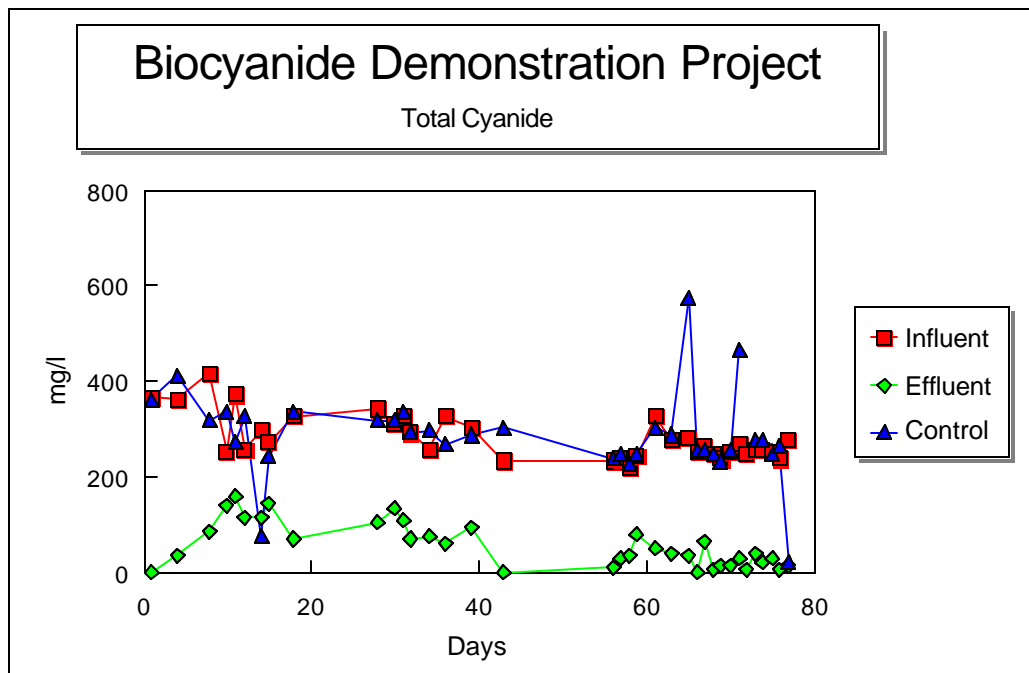


Figure 6-3. Total cyanide.



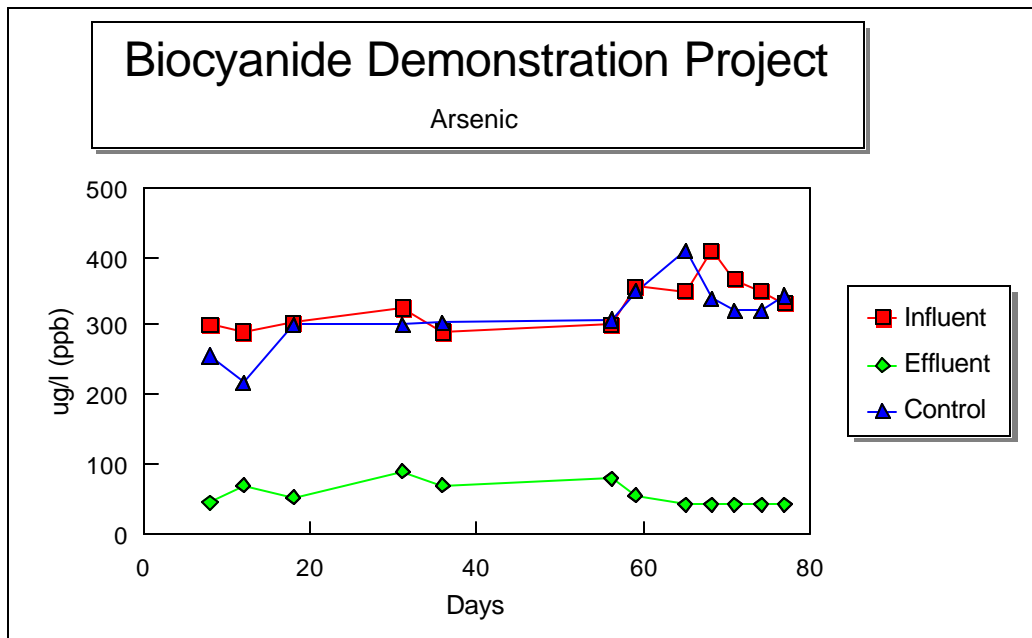


Figure 6-4. Arsenic.

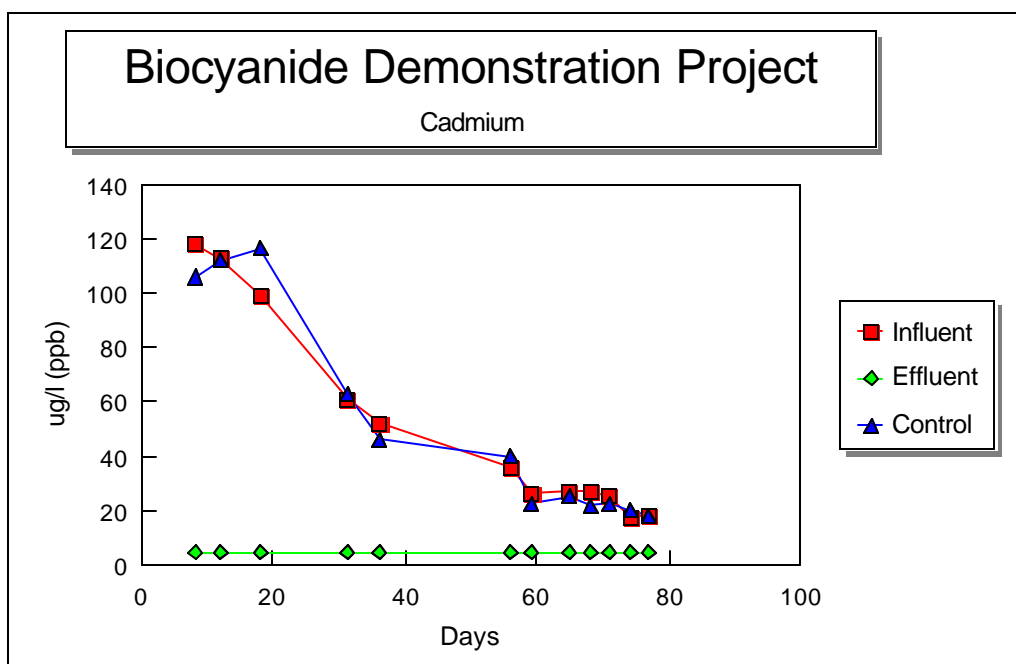


Figure 6-5. Cadmium.

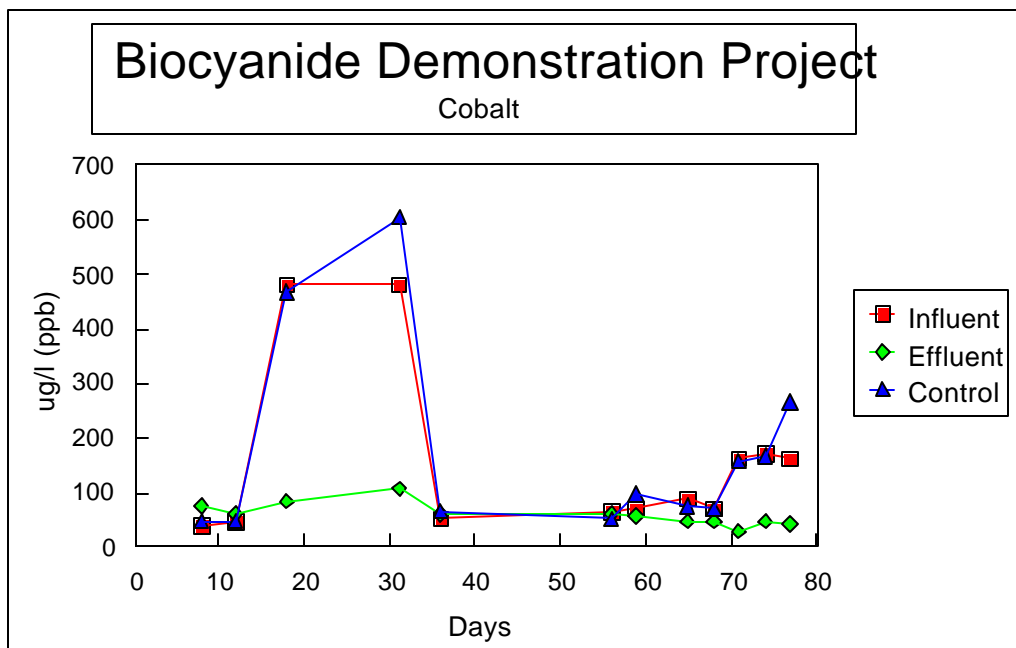


Figure 6-6. Cobalt.

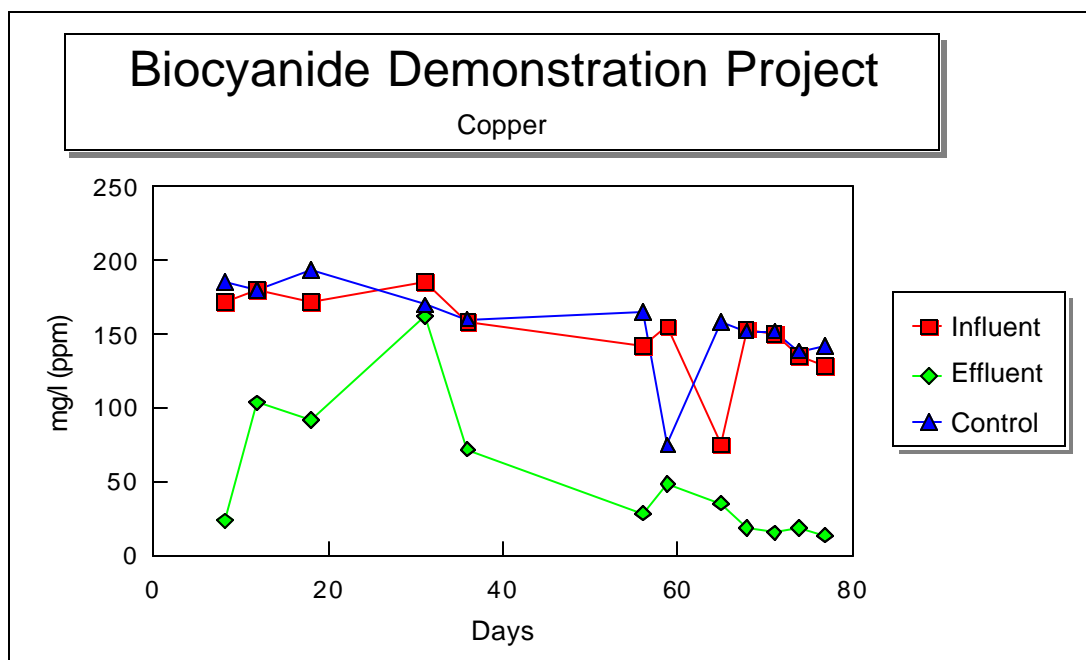


Figure 6-7. Copper.

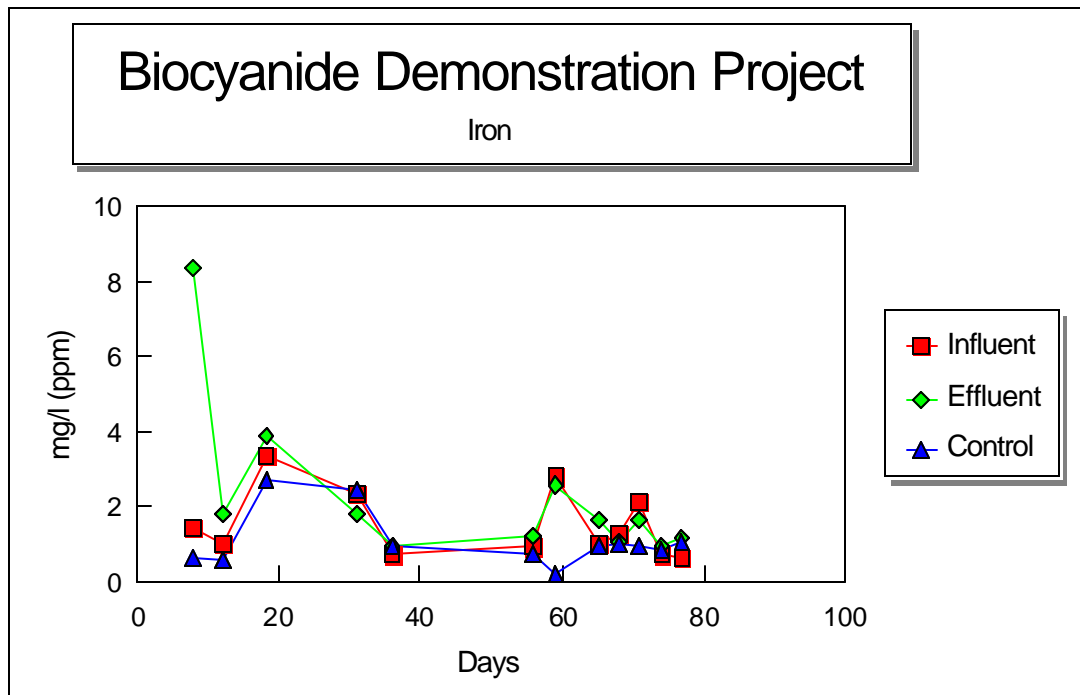


Figure 6-8. Iron.

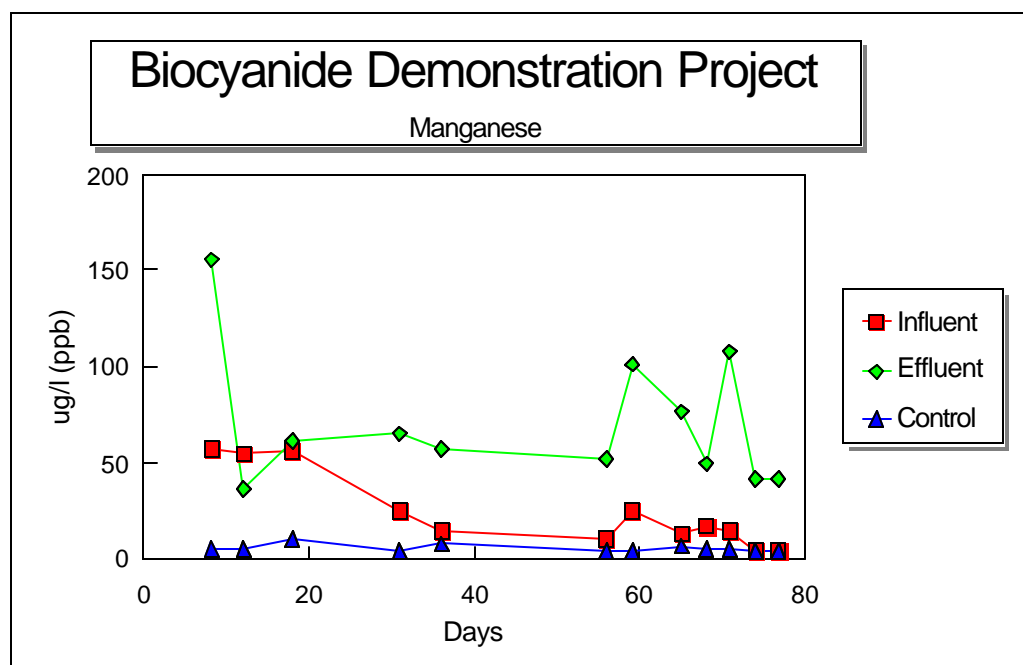


Figure 6-9. Manganese.

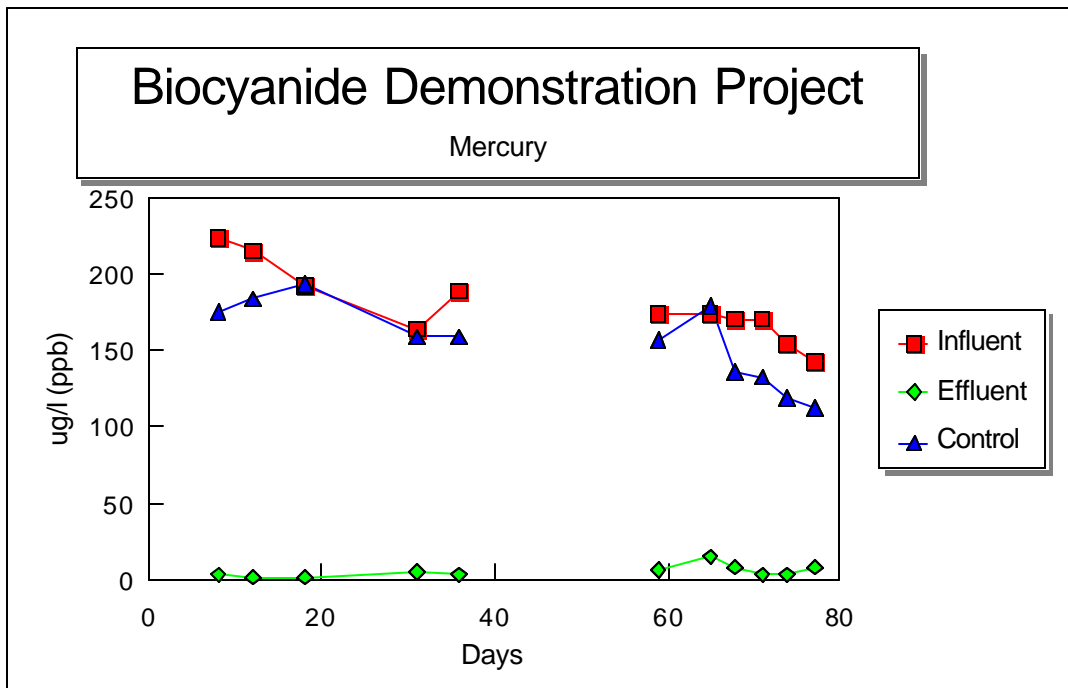


Figure 6-10. Mercury.

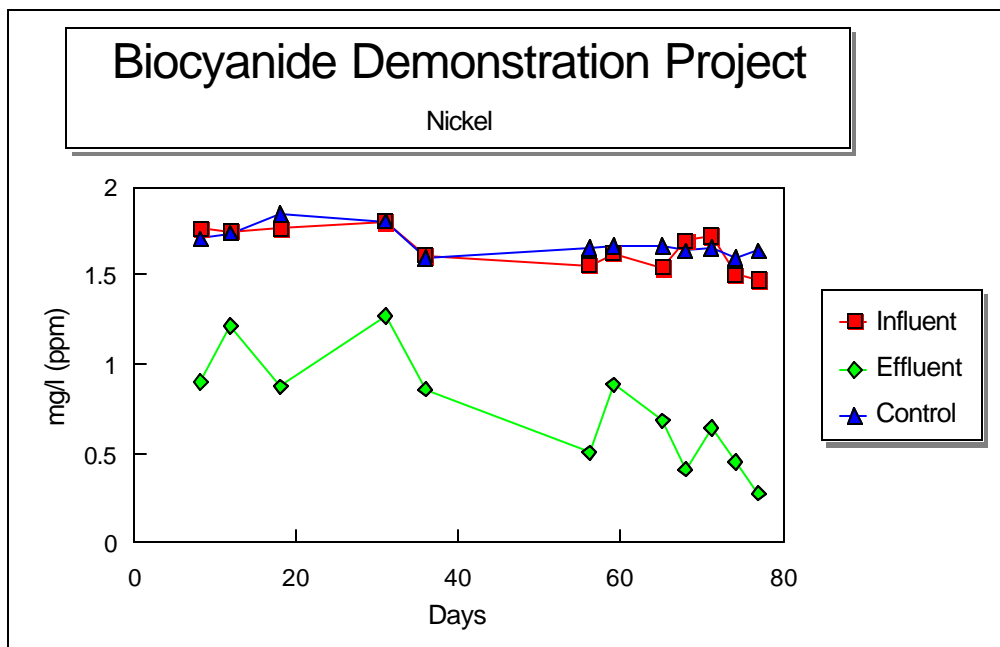


Figure 6-11. Nickel.

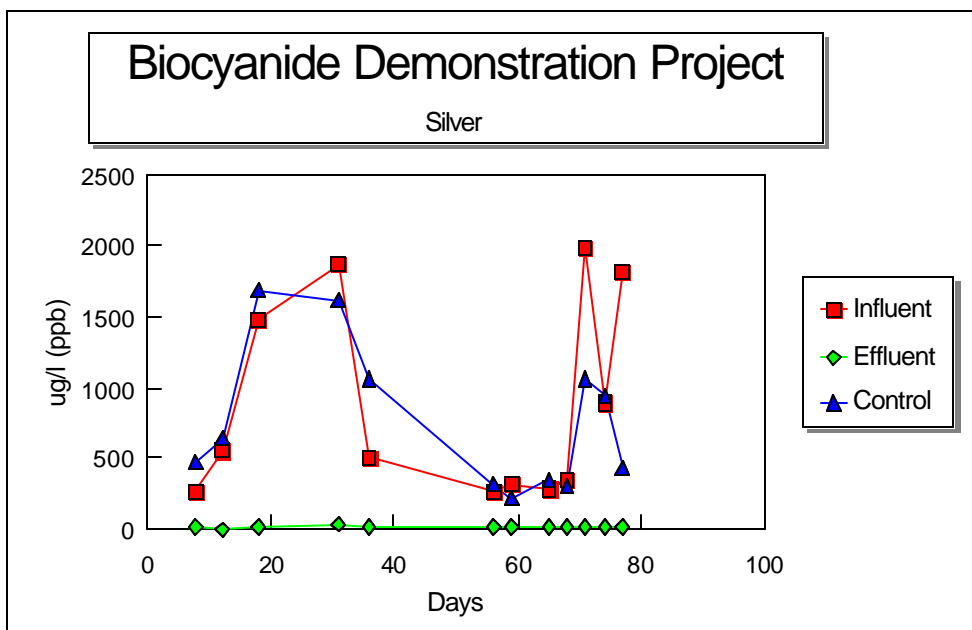


Figure 6-12. Silver.

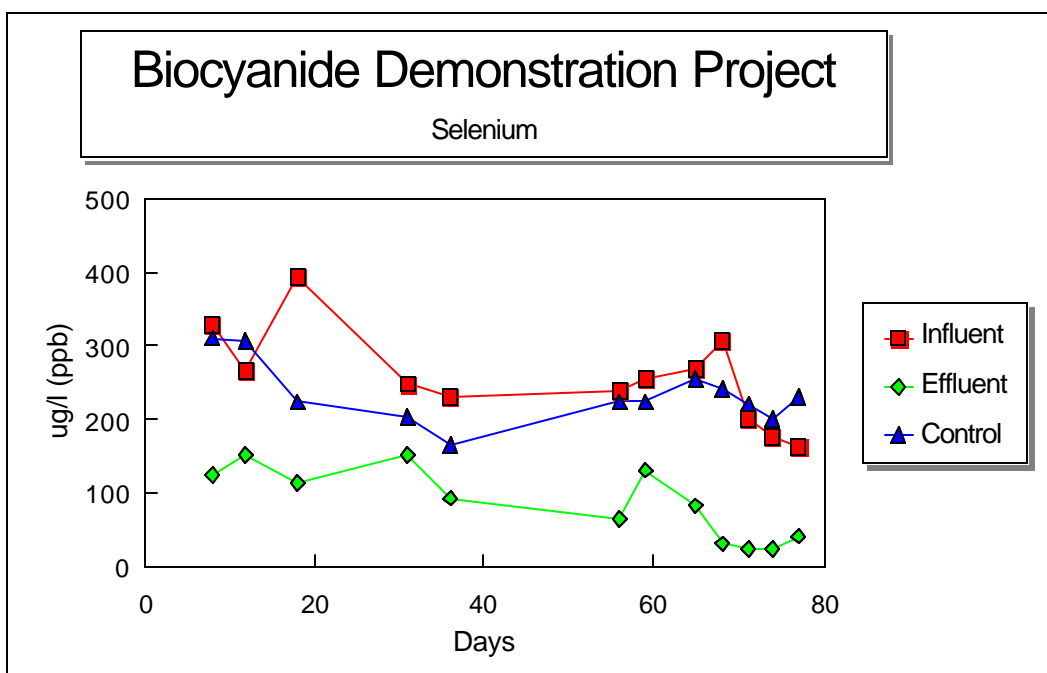


Figure 6-13. Selenium.

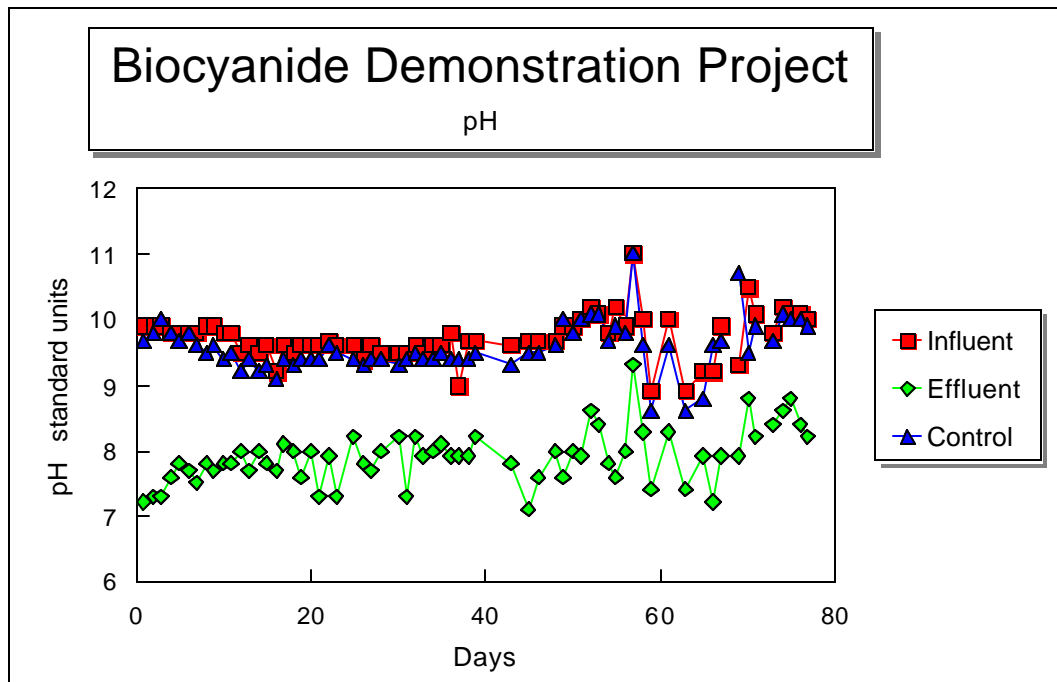


Figure 6-14. pH.

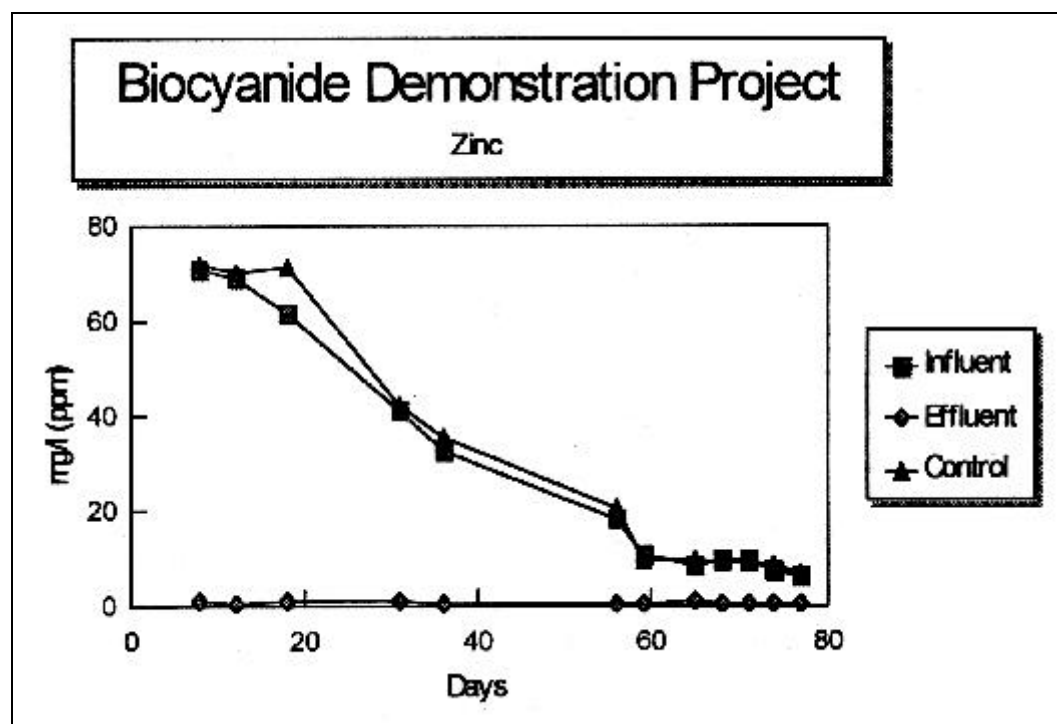


Figure 6-15. Zinc.

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## 7. Conclusions

The following conclusions were drawn from the data collected during the Biocyanide Field Demonstration:

1. Substantial reductions of ALPKEM, WAD, and total cyanide were observed over the 11-week test period. The primary project objective as described in the project-specific QAPP was to achieve an effluent WAD cyanide concentration of <1.0 mg/l with 90% statistical confidence and assuming a success rate of 90% for the technology in achieving this concentration. This objective was not met. However, the primary project objective was developed under the assumption that the influent WAD cyanide concentration would be substantially less (approximately 25 ppm) than what was experienced in the field (250 ppm). As a result, an effluent WAD cyanide concentration of 78 mg/l was met with 90% statistical confidence. Because a substantial reduction of WAD cyanide was observed even with a higher influent WAD cyanide concentration than anticipated, the biotreatment process was considered to be very successful.
2. A number of secondary project objectives were set to provide additional background data on the bioremediation process's operating characteristics, treatment capabilities, and costs. The secondary project objectives for the field demonstration were:
  - *Determine the effectiveness of the bioremediation process in reducing heavy metals in the process solution.* The metal removal efficiencies were presented and discussed in Section 6.0. Cadmium, mercury, silver, and zinc had the highest removal efficiencies followed by (in order) arsenic, selenium, copper, nickel, and cobalt. Differences in removal efficiencies were attributed to the metal-specific effectiveness of both the biomineralization process and the action of sulfate reducing bacteria. The biotreatment process was considered to be very effective in removing metals.
  - *Monitor the variation in WAD cyanide, total cyanide, and total metals in the treatment effluent during the test period.* The data for these parameters were presented in graphical and tabular form in Section 6.0. In general, the system performed better during the latter portion of the test period (7/18/97 to 8/26/97) when the system was operating more optimally.
  - *Monitor the variation in WAD cyanide in the field using the FILE method.* These WAD cyanide concentrations, also referred to as ALPKEM WAD cyanide, were presented in graphical and tabular form in Section 6.0. This data will be used by EPA as they review this method for acceptance as EPA Method 1677. This method of analysis appeared to be as reliable as the distillation method.
  - *Determine the percent reduction in WAD and total cyanides from the influent to the effluent over the test period.* The percent reductions in WAD, total, and ALPKEM WAD cyanide were presented and discussed in Section 6.0. In general, the system performed more optimally during the latter portion of the test period.
  - *Determine the loss of cyanide and metals*

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*and from the Control Reactor.* The loss of cyanide and metals from the control reactor was presented and discussed in Section 6.0. Minimal loss of cyanide and metals was noted in the control reactor.

- *Develop operating costs.* Operating costs were developed within a preliminary scale

up design. These cost are presented in Section 8.0. Biotreatment was determined to more cost-effective than conventional technologies.

The data collected during this field demonstration has provided the information needed to meet the secondary project objectives.



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## 8. Preliminary Scale-Up

### 8.1 Conceptual Full-Scale Design

A conceptual full-scale process flow diagram of a biological treatment plant to destroy cyanide has been prepared (Figure 8-1). In the full-scale system, bacterial cultures would be grown in a two-stage culture system. The microbes would be nourished with a dry nutrient feed. Periodically, fresh microbial cultures would be added to the culture tanks. The microbes would be grown in batch for 24 hours and then injected continuously into the biological treatment reactor in which cyanide would be biologically degraded. Treated waste water would be discharged from the treatment reactor.

### 8.2 Preliminary Cost Estimate

An estimate has been prepared to provide a preliminary rough cost of biological treatment (Table 8-1). This cost estimate is intended to provide information to assess the applicability of the technology for treatment of cyanide-containing mine process waters at full-scale.

The operating cost estimate assumed a flowrate of 1,000 gpm with a plant operating 24 hours/day for 300 days/year. The cost per 1,000 gallons was determined on an annualized basis of operating costs. The preliminary cost estimate to biologically treat cyanide in mine process waters at a similar concentration as seen in this demonstration is \$ 0.81 per 1,000 gallons. Table 8-1 presents the breakdown used to generate the cost estimate. It should be noted that this cost estimate reflects only a rough estimate; a larger scale plant would need to be constructed and operated in order to generate more accurate costs for a full-scale plant.

A complete economic cost comparison with other technologies was beyond the scope of this project and was not performed. However, this rough cost estimate indicates that biological treatment would offer substantial savings in operating costs over conventional treatments.

**Table 8-1. Annual Operating Cost Estimate for a Full-Scale Biological Treatment Plant**

DESCRIPTION	LABOR	NON-LABOR	TOTAL
<b>Project Support</b>			
Microbial Support	\$10,000	\$10,000	\$20,000
Nutrients		\$140,000	\$140,000
Project Oversight	\$40,000	\$20,000	\$60,000
Misc. Supplies		\$10,000	\$10,000
Analytical		\$30,000	\$30,000
Utilities		\$10,000	\$10,000
Subtotal			\$270,000
Contingency (30%)			\$81,000
TOTAL			\$351,000
Cost per 1,000 gallon-based on 1,000 gpm @ 300 days/year			\$0.81

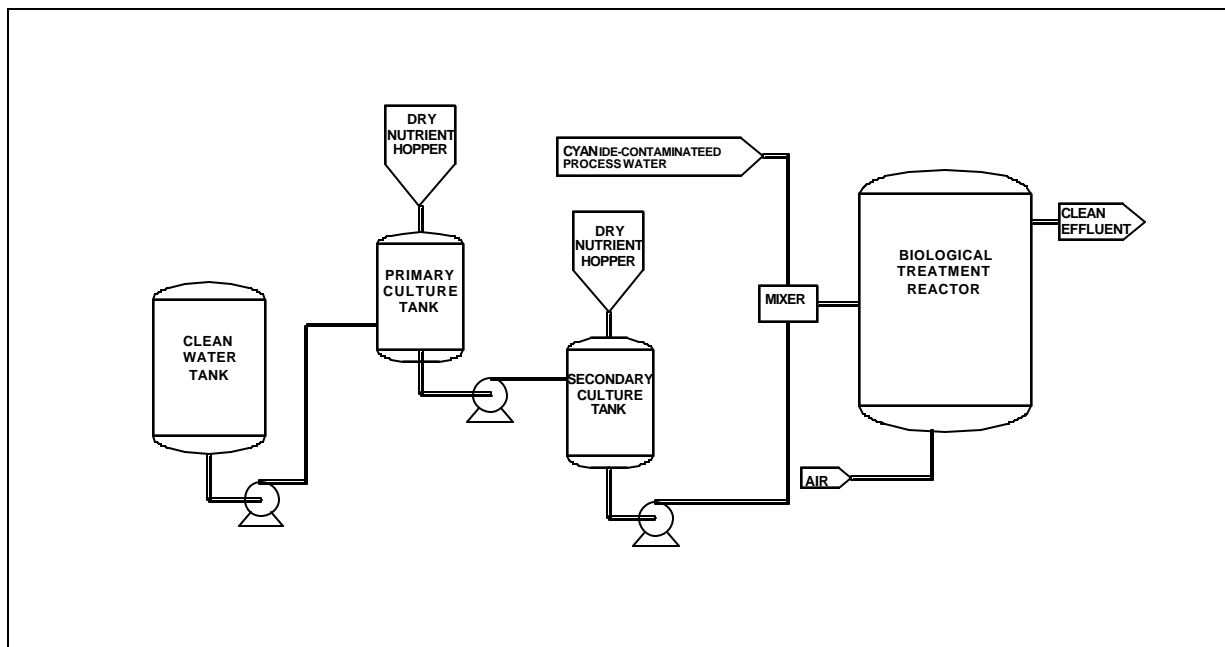


Figure 8-1. Conceptual full-scale process flow diagram of a biological treatment plant to destroy cyanide.

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## 9. References

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## **APPENDIX A**

### **Biocyanide Data**

Thiocyanide Data  
 Echo Bay, McCoy Cove  
 WAD Cyanide mg/l

Distillation WAD CN				% removal	% removal
Date	Influent	Effluent	Control	effluent	control
1 06/11/97	366	0.114	368	99.97	-0.55
4 06/14/97	378	27	390	92.86	-3.17
9 06/18/97	315	70.1	227	77.75	27.94
10 06/20/97	168	92.3	266	45.06	-58.33
11 06/21/97	343	108	202	68.51	14.87
12 06/22/97	187	91	298	51.34	-59.38
14 06/24/97	327	74.2	324	77.31	0.02
15 06/25/97	198	100	253	49.49	-27.78
18 06/28/97	287	22.5	299	92.16	-4.18
28 07/08/97	297	84	297	71.72	0.00
30 07/10/97	284	110	265	61.27	6.69
31 07/11/97	239	72	309	69.37	-29.29
32 07/12/97	279	60.4	249	78.35	10.75
34 07/14/97	262	89.2	267	65.95	-1.91
36 07/16/97	219	59.4	228	72.88	-4.11
39 07/19/97	238	90	255	66.39	-7.14
43 07/23/97	168	0.192	203	99.89	-20.83
56 08/05/97	222	8.41	191	96.21	13.96
57 08/06/97	216	26.7	229	87.94	-6.02
58 08/07/97	144	25.1	192	82.57	33.33
59 08/08/97	197	60.4	223	69.34	-13.20
61 08/10/97	294	47.7	276	83.78	6.12
63 08/12/97	257	34.7	283	86.50	-10.12
65 08/14/97	263	30.2	265	88.52	-0.76
66 08/15/97	109	0.190	247	99.90	-30.69
67 08/16/97	235	50.5	247	78.51	-5.11
68 08/17/97	200	3.71	233	98.15	-16.50
69 08/18/97	182	14.7	209	91.92	-14.84
70 08/19/97	184	13.1	241	92.88	-30.98
71 08/20/97	253	29.1	254	88.50	-0.40
72 08/21/97	217	5.44	235	97.49	-8.29
73 08/22/97	235	37.7	239	83.96	-1.70
74 08/23/97	245	23.6	211	90.37	13.88
75 08/24/97	255	27.8	240	89.10	5.88
76 08/25/97	115	2	225	98.26	-95.65
77 08/26/97	244	13.9	16.5	94.30	93.24

% > 50    % > 60    % > 70  
 13 / 35    21 / 35    27 / 35  
 37%    60%    77%

**TOTAL**

Average	242	44.3	251.3	81.33	-6.06
Std Dev	59	34.0	58.8	14.73	28.93
n		36			
90% #		30			
90% success w/90% C.L. (avg + 1 s.d.)		78.3			

**7/18 to 8/26**

Average	217	25.5	225	88.77	-7.74
Std Dev	42	20.7	52	0.90	31.96
n		21			
90% #		17			
90% success w/90% C.L. (avg + 1 s.d.)		46.2			

Biocyanide Data  
Echo Bay, McCoy/Covo  
Total Cyanide mg/l

Distillation Total CN		Influent	Effluent	Control	% Removal	
Date					Effluent	Control
1	06/11/97	366	0.194	363	99.95	0.02
4	06/14/97	362	35.1	414	90.30	-14.36
8	06/18/97	418	86.9	318	79.45	23.92
10	06/20/97	253	139	335	45.06	-32.41
11	06/21/97	370	160	271	56.76	26.76
12	06/22/97	250	110	327	55.04	-20.74
14	06/24/97	298	113	74.2	62.08	75.10
15	06/25/97	274	146	245	46.72	10.58
18	06/28/97	327	68.7	338	78.99	-3.36
28	07/08/97	341	106	317	68.91	7.04
30	07/10/97	311	136	317	56.27	-1.93
31	07/11/97	328	108	335	67.07	-2.13
32	07/12/97	293	71.6	293	75.56	0.00
34	07/14/97	260	73.1	300	71.88	-15.38
36	07/16/97	329	60.7	267	81.55	18.84
39	07/19/97	301	94.7	288	68.54	4.32
43	07/23/97	235	0.708	303	99.70	-28.94
56	08/05/97	233	10.2	239	95.62	-2.58
57	08/06/97	236	31.5	248	86.65	-5.08
58	08/07/97	221	34.1	220	84.57	-3.17
59	08/08/97	245	77.9	251	68.20	-2.45
61	08/10/97	327	51.8	301	84.16	7.95
63	08/12/97	277	42.7	289	84.58	-4.33
65	08/14/97	284	33.3	574	88.27	102.11
66	08/15/97	252	1.19	260	99.53	-3.17
67	08/16/97	262	65.2	259	75.11	1.15
68	08/17/97	248	8.17	247	96.71	0.40
69	08/18/97	240	14.5	232	93.96	3.33
70	08/19/97	255	15.5	257	93.92	-0.78
71	08/20/97	268	33.1	460	87.65	-73.88
72	08/21/97	248	7.3		97.06	100.00
73	08/22/97	260	42.1	276	83.81	-6.15
74	08/23/97	260	20.3	277	92.19	-6.54
75	08/24/97	254	28.6	248	88.74	2.36
76	08/25/97	238	3.83	265	98.39	-11.34
77	08/26/97	277	16.1	21.9	94.19	92.09

% > 90      % > 80      % > 70  
12 / 35      21 / 35      26 / 35  
34 %      60 %      74 %

**TOTAL**

Average	284	57.0	287	80.48	0.77
Std Dev	46	46.1	90	15.39	35.45
n		36			
90% #		30			
90% success w/90% C.L. (avg + 1 s.d.)		103.1			

**7/18 to 8/26**

Average	258	30.1	276	88.65	-1.85
Std Dev	24	24.9	100	9.01	41.13
n		21			
90% #		17			
90% success w/90% C.L. (avg + 1 s.d.)		55.1			

Diocyanide Data  
Echo Bay, McCoy/Cove  
PERSTORP CN mg/l

PERSTORP CN						% removal	
Date	Train	Aerobic	Influent	Effluent	Control	effluent	control
1	06/11/97	T100	388	0.43	396	99.89	-2.06
2	06/12/97	T200	350	15	372	95.71	-8.29
4	06/14/97	T200	300	25.8	208	91.40	1.33
5	06/15/97	T100	296	17.4	278	94.12	6.08
6	06/16/97	T200	283	70.8	282	74.98	0.35
7	06/17/97	T100	280	44	223	84.29	20.36
8	06/18/97	T100	268	65	254	75.84	5.58
9	06/19/97	T100	273	63.0	270	76.63	1.10
10	06/20/97	T200	304	111.2	301	63.42	0.69
11	06/21/97	T100	321	104	330	67.60	-2.80
12	06/22/97	T200	315	104	304	66.96	3.49
13	06/23/97	T100	312	132	327	57.89	-4.61
14	06/24/97	T200	301	78	292	74.09	2.59
15	06/25/97	T100	366	144	349	60.66	4.64
16	06/26/97	T200	321	161	328	49.84	-2.18
17	06/27/97	T100	278	152	262	45.32	5.70
20	07/05/97	T200	239	60	201	64.02	-9.21
26	07/06/97	T100	201	125	221	37.81	-9.95
27	07/07/97	T200	219	78	238	64.38	-8.68
28	07/08/97	T100	333	178	337	47.15	-1.20
30	07/10/97	T100	307	140	293	54.40	4.56
31	07/11/97	T200	312	107	318	65.71	-1.92
32	07/12/97	T100	297	61	201	72.73	5.39
33	07/13/97	T200	291	147	295	49.48	-1.37
34	07/14/97	T100	276	110	280	60.14	-1.45
35	07/15/97	T200	274	69	301	74.82	-9.65
36	07/16/97	T100	274	77	267	71.90	2.55
37	07/17/97	T200	277	112	274	50.57	1.08
38	07/18/97	T100	271	60	265	81.55	2.21
39	07/19/97	T200	280	85	290	69.64	-3.57
43	07/23/97	T200	238	14	273	99.41	-14.71
40	07/20/97	T200	202	40	279	64.73	-6.11
46	07/28/97	T100	232	2.0	260	98.75	-7.76
49	07/29/97	T200	266	24	283	90.98	-6.39
50	07/30/97	T100	258	18	255	82.97	0.39
51	07/31/97	T200	222	46	209	78.38	5.86
52	08/01/97	T100	244	25	255	89.75	-4.51
63	08/02/97	T200	289	13	274	95.50	5.19
56	08/05/97	T100	231	14	269	93.94	-16.45
57	08/06/97	T200	218	36	247	83.33	-14.35
58	08/07/97	T100	240	43	254	82.08	-5.83
59	08/08/97	T200	223	74	249	60.82	-11.00
61	08/10/97	T200	245	43	260	82.45	-2.04
63	08/12/97	T200	231	42	241	81.82	-4.33
65	08/14/97	T200	237	28	222	88.19	6.33
66	08/15/97	T100	236	0.018	230	99.99	2.54
67	08/16/97	T200	209	50	233	70.00	-11.46
68	08/17/97	T100	227	2.15	228	99.05	-0.44
69	08/18/97	T200	220	15	229	93.18	-4.09
70	08/19/97	T100	225	15	239	83.33	-6.22
71	08/20/97	T200	219	30	217	86.30	0.91
72	08/21/97	T100	233	7.8	247	90.05	-6.01
73	08/22/97	T200	228	38	233	84.21	2.19
74	08/23/97	T100	218	10	218	95.41	0.00
75	08/24/97	T200	215	24	201	88.84	6.51
76	08/25/97	T100	210	2.18	232	98.96	-10.48
77	08/26/97	T200	211	17.4	219	91.75	-3.79
			% rem	% > 90	% > 80	% > 70	
				18 / 56	30 / 56	39 / 56	
				32 %	54 %	70 %	
<b>TOTAL</b>							
Average			265	69.53	269	78.33	-1.89
Std Dev			43	47.95	41	16.13	6.52
n				57			
90% #				46			
90% success with 90% C.L. (avg + 1 S.D.)				107.48			
<b>7/18 to 8/26</b>							
Average			236	27.48	244	88.42	-3.88
Std Dev			21	21.05	23	8.65	0.24
n				20			
90% #				23			
90% success with 90% C.L. (avg + 1 S.D.)				48.53			

Biocyanide Data  
Echo Bay , McCoy/Cove  
Arsenic, ug/l

Day	Date	Influent	Effluent	% removal	Control	% removal
8	06/18/97	300	44.9	85.03	256	14.67
12	06/22/97	291	68.4	76.49	220	24.40
18	06/28/97	305	52.8 B	82.69	302	0.98
31	07/11/97	326	89.5	72.55	303	7.06
36	07/16/97	292 *	68.8 *	76.44	304 *	-4.11
56	08/05/97	300	79.4 B	73.53	308	-2.67
59	08/08/97	356	54.3 B	84.75	350	1.69
65	08/14/97	350	20.7 U	94.09	409	-16.86
68	08/17/96	409	20.7 U	94.94	340	16.87
71	08/20/97	368	20.7 U	94.38	324	11.96
74	08/23/97	351	20.7 U	94.10	324	7.69
77	08/26/97	334	20.7 U	93.80	342	-2.40
Average		332	46.8	85.23	315	4.94
Std Dev		35	24.7	8.50	45	10.69
Minimum		291	20.7 U	72.55	220	-16.86
Maximum		409	89.5	94.94	409	24.40
n		12	12	12	12	12



Biocyanide Data  
 Echo Bay , McCoy/Cove  
 Cadmium, ug/l

Day	Date	Influent	Effluent	% removal	Control	% removal
8	06/18/97	118	2.2 U	98.14	103	10.17
12	06/22/97	113	2.2 U	98.05	112	0.88
18	06/28/97	99.1	1.95 U	98.03	116	-17.05
31	07/11/97	60.2	1.95 U	96.76	51.9	-2.82
36	07/16/97	52	1.95 U	96.25	46.1	11.35
56	08/05/97	35.8	1.95 U	94.55	40	-11.73
59	08/08/97	25.5	1.95 U	92.35	22.6	11.37
65	08/14/97	26.5	1.95 U	92.64	25.1	5.29
68	08/17/96	27.1	1.95 U	92.80	21.2	21.77
71	08/20/97	25.1	1.95 U	92.23	22.5	10.36
74	08/23/97	17.3	1.95 U	88.73	19.9	-15.03
77	08/26/97	18	1.95 U	89.17	17.7	1.67
Average		51	2.0	94.14	51	2.18
Std Dev		36	0.1	3.20	37	11.47
Minimum		17.3	1.95 U	88.73	17.7	-17.05
Maximum		118	2.2 U	98.14	116	21.77
n		12	12	12	12	12

Biocyanide Data  
Echo Bay , McCoy/Cove  
Cobalt, ug/l

Day	Date	Influent	Effluent	% removal	Control	% removal
8	06/18/97	38.4 B	75.2	-95.83	47 B	-22.40
12	06/22/97	49.2 B	62.3	-26.63	46.8 B	4.58
18	06/28/97	481	85.8	82.16	468	2.70
31	07/11/97	482	107	77.80	605	-25.52
36	07/16/97	53.2	62.8	-18.05	64.2	-20.68
56	08/05/97	68.4	59.7	12.72	51.4	24.55
59	08/08/97	72.4	56.1	22.51	97	-33.98
65	08/14/97	89.3	48.4 B	45.80	74.3	16.80
68	08/17/96	69.3	46.4 B	33.04	69.7	-0.58
71	08/20/97	162	28.2 U	82.59	159	1.85
74	08/23/97	172	50.1	70.87	167	2.91
77	08/26/97	162	43.2 B	73.33	268	-65.43
Average		158	60	30.03	176	-9.55
Std Dev		151	20	52.66	175	23.92
Minimum		38.4	28.2 B	-95.83	46.8 B	-65.43
Maximum		482	107	82.59	605	24.55
n		12	12	12	12	12

Biocyanide Data  
Echo Bay , McCoy/Cove  
Copper, mg/l

Day	Date	Influent	Effluent	% removal	Control	% removal
8	06/18/97	172	24.5	85.76	184	-6.98
12	06/22/97	180	104	42.22	180	0.00
18	06/28/97	171	91.9	46.26	193	-12.87
31	07/11/97	184	162	11.96	170	7.61
36	07/16/97	158	72	54.43	160	-1.27
56	08/05/97	142 E	28.4 E	80.00	164 E	-15.49
59	08/08/97	155 E	48.8 E	68.52	75.5 E	51.29
65	08/14/97	75.1 E	34.5 E	54.06	158 E	-110.39
68	08/17/96	154 E	18.1 E	88.25	152 E	1.30
71	08/20/97	150	15	90.00	152	-1.33
74	08/23/97	135	19	85.93	139	-2.96
77	08/26/97	129	13	89.92	141	-9.30
Average		150	53	66.44	156	-8.37
Std Dev		28	44	23.77	29	34.87
Minimum		75.1 E	13	11.96	75.5 E	-110.39
Maximum		184	162	90.00	193	51.29
n		12	12	12	12	12

Biocyanide Data  
Echo Bay , McCoy/Cove  
Iron, mg/

Day	Date	Influent	Effluent	% removal	Control	% removal
8	06/18/97	1.44	8.34	-479.17	0.622	56.81
12	06/22/97	0.943	1.77	-87.70	0.537	43.05
18	06/28/97	3.32	3.88	-16.87	2.72	18.07
31	07/11/97	2.33	1.8	22.75	2.43	-4.29
36	07/16/97	0.713	0.889	-24.68	0.913	-28.05
56	08/05/97	0.921	1.18	-28.12	0.691	24.97
59	08/08/97	2.76	2.55	7.61	0.182	93.41
65	08/14/97	0.978	1.64	-67.69	0.901	7.87
68	08/17/96	1.28	1.05	17.97	0.989	22.73
71	08/20/97	2.1	1.63	22.38	0.872	58.48
74	08/23/97	0.71	0.861	-24.08	0.798	-12.39
77	08/26/97	0.63	1.09	-73.02	1.08	-71.43
Average		1.51	2.23	-60.89	1.06	17.44
Std Dev		0.86	2.01	131.14	0.72	42.00
Minimum		0.63	0.881	-479.17	0.182	-71.43
Maximum		3.32	8.34	22.75	2.72	93.41
n		12	12	12	12	12

Biocyanide Data  
 Echo Bay , McCoy/Cove  
 Manganese, ug/l

Day	Date	Influent	Effluent	% removal	Control	% removal
8	06/18/97	56.9	156	-174.17	5.3	90.69
12	06/22/97	54.4	36.4	33.09	5.4 B	90.07
18	06/28/97	56.5	60.7	-7.43	10.7 B	81.06
31	07/11/97	24.4	65.2	-167.21	4 B	83.61
36	07/16/97	13.8 B	57.3	-315.22	8.3	39.86
56	08/05/97	10.4 B	52.6	-405.77	1.75 U	83.17
59	08/08/97	24.8	102	-311.29	1.75 U	92.94
65	08/14/97	13.7 B	76.1	-455.47	6.4 B	53.28
68	08/17/96	17.7	49.4	-179.10	5.6 B	68.36
71	08/20/97	14.2 B	108	-660.56	5 B	64.79
74	08/23/97	1.75 U	41.5	-2271.43	1.75 U	0.00
77	08/26/97	1.75 U	41.5	-2271.43	1.75 U	0.00
Average		24.2	70.6	-598.83	4.8	74.78
Std Dev		19.5	33.7	769.84	2.7	16.61
Minimum		1.75 U	36.4	-2271.43	1.75 U	39.86
Maximum		56.9	156	33.09	10.7 B	92.94
n		12	12	12	12	10

Biocyanide Data  
 Echo Bay , McCoy/Cove  
 Mercury, ug/l

Day	Date	Influent	Effluent	% removal	Control	% removal
8	06/18/97	223 N	2.8 N	98.74	175 N	21.52
12	06/22/97	215	1.2	99.44	184	14.42
18	06/28/97	191 N	1.8 N	99.16	193 N	-1.05
31	07/11/97	164	4.8	97.20	158	3.66
36	07/16/97	188 N	2.8 N	98.46	159 N	15.43
59	08/08/97	174	7	95.98	157	9.77
65	08/14/97	174	14.3	91.78	178	-2.30
68	08/17/98	170	7.3	95.71	136	20.00
71	08/20/97	171	3.4	98.01	133	22.22
74	08/23/97	153	3	98.04	119	22.22
77	08/26/97	142	7.9	94.44	112	21.13
Average		179	5.1	97.00	155	13.37
Std Dev		23	3.6	2.23	26	9.01
Minimum		142	1.2	91.78	112	-2.30
Maximum		223 N	14.3	99.44	193 N	22.22
n		11	11	11	11	11

Biocyanide Data  
 Echo Bay , McCoy/Cove  
 Nickel, mg/l

Day	Date	Influent	Effluent	% removal	Control	% removal
8	06/18/97	1.77	0.909	48.64	1.71	3.39
12	06/22/97	1.75	1.22	30.29	1.73	1.14
18	06/28/97	1.77	0.878	50.40	1.85	-4.52
31	07/11/97	1.8	1.27	29.44	1.8	0.00
36	07/16/97	1.62	0.867	46.48	1.6	1.23
56	08/05/97	1.56 E	0.51 E	67.31	1.66 E	-6.41
59	08/08/97	1.63 E	0.89 E	45.40	1.67 E	-2.46
65	08/14/97	1.55 E	0.686 E	55.74	1.67 E	-7.74
68	08/17/96	1.7 E	0.409 E	75.94	1.64 E	3.53
71	08/20/97	1.72	0.638	62.91	1.66	3.49
74	08/23/97	1.51	0.457	69.74	1.6	-5.96
77	08/26/97	1.47	0.276	81.22	1.64	-11.56
Average		1.65	0.75	55.29	1.69	-2.16
Std Dev		0.11	0.30	15.94	0.07	4.83
Minimum		1.47	0.276	29.44	1.6	-11.56
Maximum		1.8	1.27	81.22	1.85	3.53
n		12	12	12	12	12

Biocyanide Data  
 Echo Bay, McCoy/Cove  
 Selenium, ug/l

Day	Date	Influent	Effluent	% removal	Control	% removal
8	06/18/97	325 B	123	62.15	308 B	5.23
12	06/22/97	264 B	151	42.80	305 B	-15.53
18	06/28/97	391	113	71.10	222	43.22
31	07/11/97	246	151	38.62	202	17.89
36	07/16/97	232 U	91.9 B	60.39	166	28.45
56	08/05/97	238	65.4	72.52	223	6.30
59	08/08/97	255	132	48.24	225	11.76
65	08/14/97	287	82.2	69.21	253	5.24
68	08/17/96	305	29.6 B	90.30	242	20.66
71	08/20/97	199	11.6 U	94.17	219	-10.05
74	08/23/97	175	25.5 B	85.43	200	-14.29
77	08/26/97	163	42.3 B	74.05	232	-42.33
Average		255	84.9	67.41	233	4.71
Std Dev		61	47.8	17.15	39	21.85
Minimum		163	11.6 U	38.62	166	-42.33
Maximum		391	151	94.17	308 B	43.22
n		12	12	12	12	12



Biocyanide Data  
Echo Bay , McCoy/Cove  
Silver, ug/l

Day	Date	Influent	Effluent	% removal	Control	% removal
8	06/18/97	267	15.9	94.04	471	-76.40
12	06/22/97	560	4.9 B	99.13	631	-12.68
18	06/28/97	1480	12.1	99.18	1680	-13.51
31	07/11/97	1860	33	98.23	1620	12.90
36	07/16/97	507	11.2	97.79	1060	-109.07
56	08/05/97	270 E	7.5 B	97.22	323 E	-19.63
59	08/08/97	320 E	17.2 E	94.63	215 E	32.81
65	08/14/97	281 E	19.8 F	92.95	357 E	-27.05
68	08/17/96	357 E	23 E	93.56	297 E	16.81
71	08/20/97	1980	8.9 B	99.55	1060	46.46
74	08/23/97	897	12	98.66	933	-4.01
77	08/26/97	1810	19.5	98.92	431	76.19
Average		862	15.4	96.99	757	-6.43
Std Dev		667	7.4	2.36	489	48.48
Minimum		267	4.9 B	92.95	215 E	-109.07
Maximum		1980	33	99.55	1680	76.19
n		12	12	12	12	12

Biocyanide Data  
 Echo Bay , McCoy/Cove  
 Zinc, µg/

Day	Date	Influent	Effluent	% removal	Control	% removal
8	06/18/97	70.7 E	0.7 E	99.01	71.7 E	-1.41
12	06/22/97	68.9	0.401	99.42	70.2	-1.89
18	06/28/97	61.7	0.998	98.38	70.9	-14.91
31	07/11/97	41	0.845	97.94	41.8	-1.95
36	07/16/97	32.6	0.621	98.10	35.1	-7.67
56	08/05/97	18.1	0.531	97.07	20.5	-13.26
60	08/08/97	10.6	0.635	94.01	9.21	13.11
65	08/14/97	8.43	0.712	91.55	9.38	-11.27
68	08/17/96	9.66	0.351	96.37	8.89	7.97
71	08/20/97	9.37	0.555	94.08	8.92	4.80
74	08/23/97	7.18	0.25	96.52	8.15	-13.51
77	08/26/97	6.34	0.287	95.47	6.89	-8.68
Average		29	0.57	96.49	30.1	-4.05
Std Dev		24	0.22	2.25	25.9	8.72
Minimum		6.34	0.25	91.55	6.89	-14.91
Maximum		70.7 E	0.998	99.42	71.7 E	13.11
n		12	12	12	12	12

